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ORBITAL AND METEOROLOGICAL FACTORS PERTINENT TO SATELLITE TRANSMISSIONS OF FACSIMILE WEATHER CHARTS

ARTHUR R. HALL
ROMEO R. SABATINI
JOHN E. SISSALA
LOUIS NOVOTNY

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ARACON GEOPHYSICS CO.
VIRGINIA ROAD, CONCORD, MASSACHUSETTS
DIVISION OF ALLIED RESEARCH ASSOCIATES, INC.

FOREWORD

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Although the final study represents the combined efforts of all authors, credits for the various sections of this report are primarily attributable as follows:

Arthur R. Hall: Sections 1, 2, 3, 5, 6, 7, 8, Appendices A and B

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Romeo R. Sabatini: 3. 1, 3. 2, 3. 4, 4

John E. Sissala: 3, 4, 6, Appendix D

ABSTRACT

The feasibility of using the APT system, on both Nimbus-type and earth-synchronous satellites, for the transmission of weather charts (WEFAX) has been studied, with particular reference to orbital and meteorological factors. The study included an analysis of prospective WEFAX customers. It is shown that such a system of weather chart transmission is feasible, and that it would particularly benefit those areas that have inadequate radio or landline facsimile coverage.

It appears that WEFAX transmissions would occur principally during daytime, between APT pictures. It is concluded that a 750 n.mi. sun-synchronous orbit would permit an adequate WEFAX transmission (an 8" x 11" area on the Fairchild APT recorder) between APT pictures, without sacrificing useful APT picture coverage. An earth-synchronous satellite, with 20 or 25 minutes of WEFAX transmissions every six hours, could provide useful basic weather charts for the entire area where its transmissions can be received. The transmissions of WEFAX along a sun-synchronous orbit would be divided into Tropical, Mid-latitude, and Polar chart areas. The chart areas transmitted would be modified every 30 degrees of longitude for the Tropical and Mid-latitude charts, and every 60 degrees of longitude for the Polar charts. It is recommended that each 8" x 11" WEFAX transmission (frame) be divided into two 8" x 5½" charts. Such charts would provide adequate detail using a 1:30 million Polar stereographic projection for middle and high latitudes, and a 1:40 million Mercator projection for the Tropics.

In general, the most useful weather charts are a surface analysis and an upper air analysis (usually 500 mb, but often 200 mb in the tropics), and prognoses for similar levels. These charts would be given priority when scheduling transmissions. It also appears possible and advantageous to superimpose a simplified surface and an upper air analysis or prognosis in some situations, thereby increasing the number and variety of charts receivable by certain stations.

Weather chart selections recommended for transmission, for various single and multiple satellite configurations, are presented, used to develop programs, and illustrated by full scale typical maps, and by maps depicting the recommended geographical areas of coverage.

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1. INTRODUCTION

Since the launch of TIROS I in April 1960, meteorological satellites have been gathering information with various sensors, and have been transmitting their observations to ground receiving stations. Now, more than five years after that launch, transmission of analyzed weather charts by means of meteorological satellites (which was first suggested several years ago) is being actively considered. The Goddard Space Flight Center (GSFC) of NASA, and its contractors[6], are investigating modifications to the Automatic Picture Transmission (APT) system such that charts and other meteorological data could be transmitted from the ground to a satellite, and subsequently relayed to ground stations possessing an APT receiver. Standard weather charts would be coded in a facsimile mode, and the signals then transmitted to and stored in near-earth meteorological satellites. On a programmed basis, charts appropriate to specific geographical areas would then be relayed by the APT transmitters to APT receiving sets within range. GSFC is also studying the feasibility of relaying analyzed weather charts, in real time, by means of an earth-synchronous satellite system. These modes of using the APT system have been given the nickname "WEFAX."

The technical feasibility of the WEFAX mode of operation was demonstrated by the SCORE and COURIER satellites. The successful operation of the TIROS VIII and NIMBUS I APT systems leaves little question of the feasibility of using the APT transmitter and standard APT ground stations to handle these additional meteorological data, especially since standard weather charts require only differentiating between black lines (or symbols) and white areas, with no gray scale discrimination needed.

The basic capability of a WEFAX system could also, of course, be used to transmit a wide variety of other types of graphic material providing that (1) the scanner unit has an appropriate gray scale capability, (2) the material can be fitted in the available transmission times, and (3) the size of any characters or symbols is sufficient to be legible after transmission and recording. This capability might, for example, be used to disseminate instructions or program advices relating to WEFAX tests or operations.

This study, which is only one part of the overall GSFC WEFAX development program, is primarily concerned with the three following principal questions (each containing its own secondary problems) which must be resolved before the worth of such a system can be demonstrated.

1. Who would be the prospective customers, and what are their most critical requirements that WEFAX might satisfy?

2. How many and what types of charts should and can be transmitted?

3. How much time is there available for transmitting such charts, and what are the optimum programs for such transmissions?

To this end, Section 2 examines the matter of Customer Identification. In Section 3, the factors influencing WEFAX chart transmissions from sun-synchronous satellites are investigated, leading to a set of recommended geographical areas and scales for the charts to be transmitted. Section 4 examines the analogous, but far simpler, problems for the case of earth-synchronous satellites.

Section 5 establishes a priority as to the types and formats of the charts to be transmitted as a function of the total lengths of available daily transmissions for various latitudes. Combining the results of either Section 3 or Section 4, and Section 5, Section 6 develops specific chart selections for various combinations of satellites.

In Chapter 7, these selections are used to develop specific transmission programs; and the numbers and types of charts available to typical stations, using these recommended programs, are tabulated. Section 8 discusses several further preparative steps, and further subsidiary investigations, that appear desirable prior to the launch of the first WEFAX satellite.

The material in the body of the report is augmented by four appendices.

Before moving to the specific discussions of the investigations made and the results obtained, it is worthy of note that the transmission of weather charts by use of the APT system (WEFAX) would directly assist the United States in satisfying that portion of its intentions, or of any obligations, under the World Weather Watch program, which call for the dissemination of analyses and prognoses to the meteorological services of the various nations. It also provides an excellent opportunity to further those United States foreign policy aims which concern: (1) providing assistance to emerging nations so that they may advance economically, socially, and politically; and (2) improving and strengthening institutions of international cooperation.

2. CUSTOMER IDENTIFICATION

To ascertain which areas of the earth would most benefit from receiving facsimile weather charts by satellite transmission (WEFAX), a study was made of the known existing and planned Automatic Picture Transmission (APT) receiving stations, and of the locations of the major radio stations making facsimile weather broadcasts. The locations of the APT stations are shown in Figure 2-1 and listed in Appendix A. The locations of the major radio stations transmitting facsimile weather charts are shown in Figure 2-2 and listed in Appendix B.

2.1 Numbers and Locations of APT Stations

The definitely foreseeable number of APT stations, including both those presently in existence and those planned for installation within the next year (based on information available as of about October 1965), is 128. These include fixed, remote, and mobile APT stations. Figure 2-1 indicates the locations of these APT stations; each dot represents one station except where several stations are concentrated in a small area. In such cases, a number has been placed adjacent to a dot to represent the total number of stations in that area. The parenthetical 2's in the Atlantic and Pacific oceans represent APT sets installed on ships of the U.S. Navy.

As can be seen in Figure 2-1, the heavier concentrations of APT stations are in the continental United States, Europe, and southeast Asia. Of the 128 existing or programmed APT sets, 57 (about 45%) are or will be located in the continental United States.

Figure 2-1 presents only the lower limit of the existing and planned APT stations, since identification of all existing and planned APT stations cannot be assured, especially in the case of foreign countries. Foreign countries may order APT sets from various manufacturers (some in foreign countries), and we may not learn of these orders unless the countries ask NASA or the Environmental Science Services Administration (ESSA) for information or guidance. No information could be obtained on the subject of APT stations existing in or planned by the U. S. S. R. It is understood that the Soviets are planning to launch a meteorological satellite late in 1965. If they have not already developed an APT system, it can be assumed that they could in the near future. Their APT sets could easily be designed to receive information transmitted by United States' APT systems, since all information necessary for the independent development of APT receiving stations has been made available to the international meteorological community.

Additional APT sets will probably be furnished to some of the less developed nations through assistance programs of the United Nations, the World Meteorological Organization, and the United States. The United States expects to provide APT readout stations, through its Foreign Assistance Program, to some of these countries where the technical capability for making effective use of such equipment exists. As APT stations are installed in less developed nations, the addition of facsimile weather charts to the APT transmissions would materially assist the meteorological services of those countries.

2.2 Radio Facsimile Coverage

The major radio stations which are presently used for broadcasting facsimile weather charts are shown in Figure 2-2. A list of these stations, along with their locations, call signs, antenna powers, frequencies, and transmitting times, has been included as Appendix B.

It is obvious from Figure 2-2 that the areas of relatively good radio facsimile coverage are North America and Europe, and that there is at least fair coverage for most of the North Pacific Ocean, the North Atlantic Ocean, northern Africa, extreme eastern Asia, and Australia. Much of South America, Africa, southern Asia, and the tropics and most of the southern hemisphere oceans appear to have rather poor radio facsimile coverage. Little information could be obtained on the radio facsimile coverage in the U.S.S.R.; it can be assumed, with broadcast stations at Moscow and Khabarovsk, that the facsimile coverage is adequate.

There are a few other, smaller radio facsimile broadcast stations which do not appear in Figure 2-2 or Appendix B. These stations are not mentioned in any of the available publications (see Refs. 1, 2, 3, and 4). These smaller stations are generally limited to transmitting facsimile weather charts within the country in which the transmitting station is located. For example, Canada makes special transmissions to its Arctic areas during the summer resupply period. Some countries (mainly those in North America and Europe where there are well developed communication facilities) use landlines for the transmission of facsimile weather charts within the country, and in a few cases between countries.

It was originally expected that the station locations in Figure 2-2 would be augmented by range of reception circles to better depict the areas inadequately served by present radio facsimile transmissions. This has, however, not been feasible. Due to the number of possible variables in transmitter antenna patterns

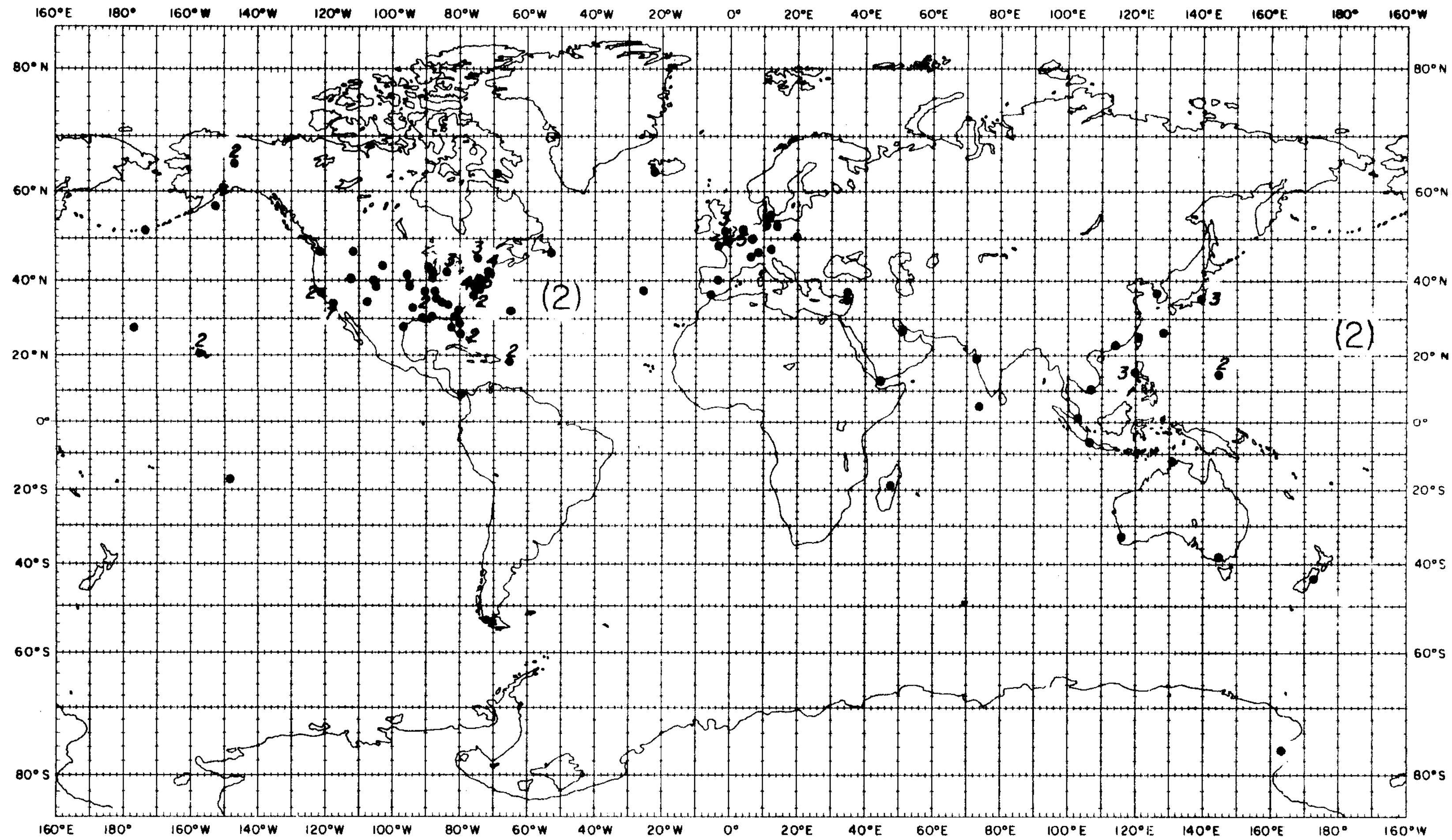

Figure 2-1 Locations of APT Receivers (Fixed, Remote and Mobile).

and the unavailability of some of the technical information needed, it has seemed best to limit the presentation of the areal coverage of radio facsimile to a depiction of the locations and density of radio facsimile transmitting stations. The amount of detailed information needed to reliably determine the radio facsimile coverage circles could not have been assembled and processed during the period of performance of this study. During the consideration of this aspect of customer identification, however, a possible approach to crude estimates of probable radii of reception was developed. Although the range of probable errors in this approach is considered too great to merit direct use in this customer identification analysis, the technique and those approximate conclusions derived from its application are included as Appendix C. If desired, the technique, in spite of its obvious deficiencies, could later be applied to provide a very slightly better first estimate of areas lacking radio facsimile coverage.

2.3 Plans of the World Meteorological Organization

Plans developed by the World Meteorological Organization (WMO) Commission for Synoptic Meteorology and the United States Interagency Committee for International Meteorological Programs (Ref. 5) call for a global meteorological communications system for the world-wide exchange of meteorological information. The plan calls for five centers in the northern hemisphere, and three in the southern hemisphere (see Figure 2-3):

Northern Hemisphere	Southern Hemisphere
New York, U.S.A.	Brasilia, Brazil
Offenbach, Germany	Nairobi, Kenya
Moscow, U.S.S.R.	Melbourne, Australia
New Delhi, India	
Tokyo, Japan	

The northern hemisphere exchange centers are presently connected by means of landline, cable, and/or radio. The inter-hemisphere circuits between New York and Brasilia, and between New Delhi and Melbourne, are not as yet connected. The Offenbach-Nairobi connection circuit is functioning only for southbound traffic. From the information available, it is reasonable to assume that this global meteorological communications system will not be fully implemented before 1970.

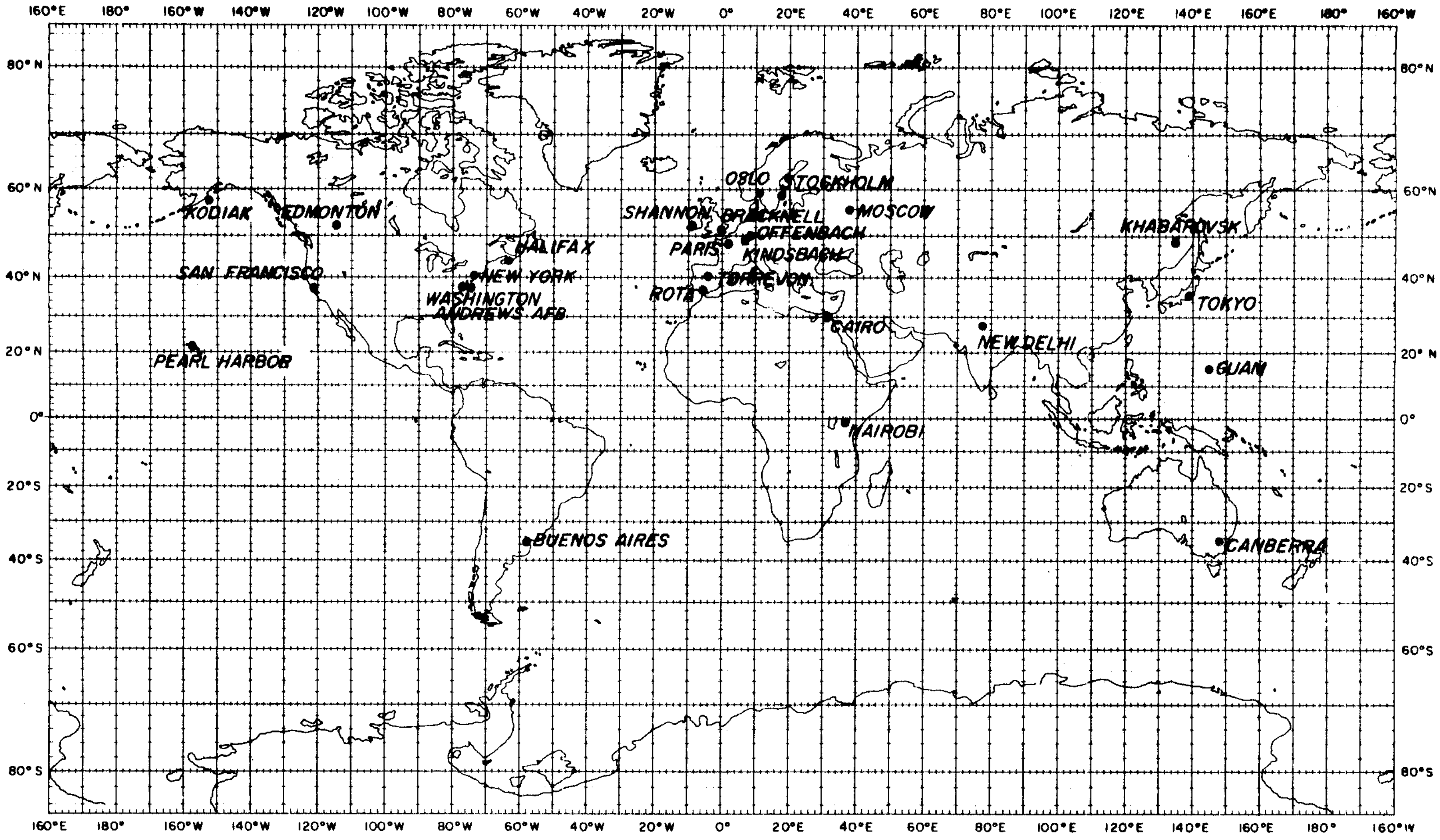

Figure 2-2 Locations of Major Radio Stations Making Facsimile Weather Chart Transmissions.

A World Weather System (also known as the World Weather Watch) is planned with World Centers at Washington, Moscow, and Melbourne. The World Weather System includes national and international efforts for making appropriate meteorological observations and analyses available to world, regional, and national centers; for the processing of the observations and the preparation of analyses and prognoses; and for the distribution of these products to those national meteorological services that desire them. The Washington and Moscow World Centers are already connected by cable, and are exchanging both digital and graphic meteorological information. A cable will also be installed between the Washington and Melbourne World Centers. At present, weather satellite nephanalyses are being transmitted on special occasions by radio facsimile from Washington, through San Francisco, to Melbourne.

In general, it would appear that these WMO programs will do much to improve global analyses, and the delivery of these analyses to regional centers and to those national weather centers and stations tied to the regional centers by adequate communications. They will, however, be of lesser assistance to remote local stations whose communications limit them to the reception of unanalyzed synoptic data (usually those for their local region) and coded map analyses, which provide only limited information and require laborious decoding and plotting before they are ready for use.

2.4 Communication Economics

In order to permit cost comparisons between APT, radio facsimile, and leased-land-line facsimile receiving stations, a study of equipment prices was made. Available literature and conversations with reliable sources were used for this study. Complexities, which arise from variable performance of the equipments and therefore lead to variability in prices, preclude a truly objective comparison.

Current prices of radio facsimile receiving equipment vary from about \$6,000 for a relatively short range receiving set to about \$50,000 for a sophisticated long range receiving station. Prices of APT sets range from less than \$8,000 to over \$33,000. Do-it-yourself APT sets can be locally constructed from standard electronic components (facsimile recorder excluded) at a reduction in basic cost of possibly one-third or more; this is especially likely in areas where labor costs are relatively low. Alden Company markets a portable or mobile APT set costing just under \$8,000. This includes a dual mode (APT and Weather Chart) facsimile recorder, which in weather chart mode is compatible with the U.S. Weather Bureau transmissions. Hardware for a radio facsimile receiving

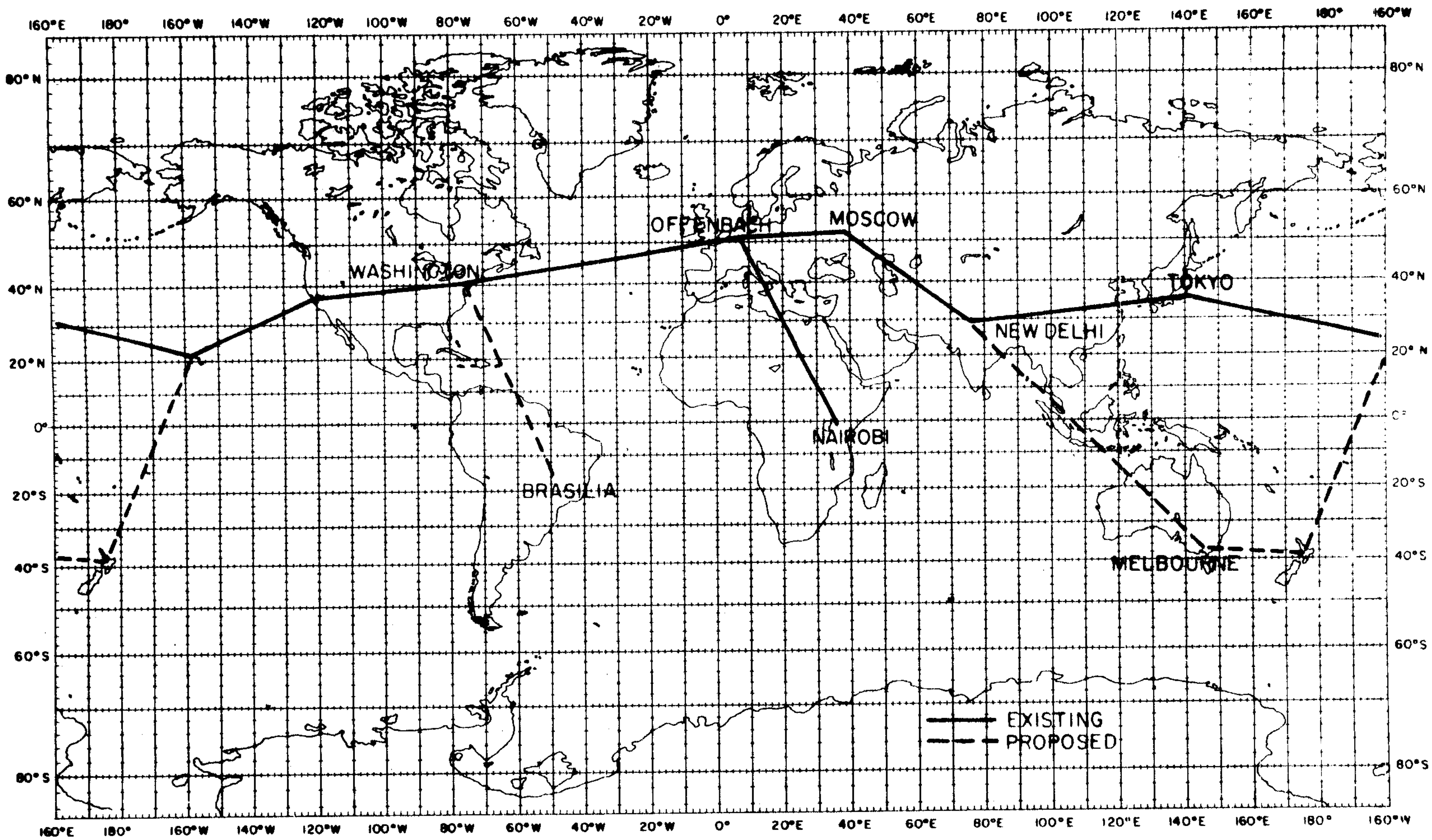

Figure 2-3 Existing and Proposed WMO Global Meteorological Communications System.

station capable of 2,000 to 3,000 mile reception is compatible in price with the Alden APT set. When recurrent land-line charges are considered, a leased-line facsimile station is also compatible in price with an APT set or a radiofacsimile receiving unit to a distance of about 90 miles from the source or from the next station on the circuit; beyond that, the land-line costs become excessive.

Some of the nations of the world not now so equipped plan on installing weather facsimile receivers. If these countries could be assured of receiving sufficient, timely, and useful facsimile weather charts via APT, they might obtain APT sets rather than installing landline or radio facsimile.

In this regard, it becomes desirable to further explore the matter of "sufficient" weather charts. As will be demonstrated in subsequent sections of this report, WEFAX transmissions in the time intervals between APT pictures (during daylight) or in otherwise unused night periods (in the absence of DRIR transmissions) from sun-synchronous satellites can provide a global distribution of a significantly useful number of the most critical weather charts. A similar capability exists for earth-synchronous satellites whose WEFAX transmissions are limited to a small fraction of a day; in this case, of course, the degree of global capability depends on the number and geographical positions of the concurrently operating earth-synchronous satellites.

In contrast, most land-line and radio facsimile transmissions operate on an essentially continuous schedule which occupies nearly the full 24 hours of each day. This permits the transmission of a wide variety of charts at such recurrent intervals as are made appropriate by the scheduled synoptic hours of observation (the intervals are usually six or twelve hours), and by the relative operational significance of the different types of charts. There is apparently a significant operational demand for each and every one of these charts, since a major controversy ensues following any proposal to delete an existing chart in favor of a new one. (In this regard, recall the difficulties that existed in obtaining time for satellite nephanalysis transmissions during the first several years of the TIROS programs.) In fact, the demand for chart variety and frequency is so great that the U. S. Weather Bureau operates two concurrent land-line facsimile circuits within the continental United States; one to all stations and the other to provide additional charts to major forecast centers.

With this background in mind, it seems unlikely that a limited WEFAX capability (such as would be available from charts interspersed between APT pictures, or limited transmissions from earth synchronous satellites) can ever be competitive with land-line or radio facsimile where sufficient communications exist, or for nations which are able to consider the costs of reasonably adequate weather information dissemination as secondary to the need for obtaining and distributing the data.

On the other hand, if a capability for full time WEFAX transmissions from earth-synchronous satellites were to be implemented, it would often be fully competitive with land-line or radio facsimile systems. This would certainly be true in most of the remote or less developed areas of the world. Even in the continental United States, such a system would merit full consideration, especially if an additional facsimile circuit, or major equipment replacements over an existing circuit, were contemplated. *

2.5 Potential WEFAX Customers

The WEFAX capability, even when very limited in the number and variety of charts it can disseminate each day, can particularly benefit the smaller, remote weather stations whose professional manning may range from a single forecaster to no more than one forecaster per shift. ** To a greater or lesser degree, such a station will receive weather observations for its immediate vicinity--say a radius of the order of 500 miles--by existing conventional communications. It can use to significant advantage regional analyses and prognoses prepared by an adequately staffed center, and covering an area surrounding the station and of the order of 5-10 million square miles. In many cases, existing communications do not provide such analyses, or provide them only in forms requiring laborious reception and decoding procedures. The WEFAX charts would supplement the local area information and would improve the reliability of the forecasts issued by such stations, especially in the period of 24 to 48 hours.

APT sets have already been installed in many weather stations which are larger than those mentioned above. These larger stations may also receive some benefit from the weather charts received by WEFAX, especially in areas where there is a lack of suitable facsimile reception.

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* Other aspects of these matters are also discussed in Appendix C (Section 3. 8. 5. 1) and Appendix D (page 3) of Reference 5.

** It is to be noted that, in many countries, a station of this size may well be the major or even the only weather station in the country.

By comparing Figures 2-1 and 2-2, it is apparent that the heavier concentrations of APT stations are presently in areas of good facsimile coverage. The main exception to this is the area of southeast Asia, where there is a fair network of APT stations. It appears, from the present locations of APT receivers, that the area of southern and southeast Asia would greatly benefit from the transmission of weather charts utilizing the APT system. However, there are many more countries, such as those in South American and Africa, which, with the acquisition of APT sets, would also receive great benefits from the proposed WEFAX system. There are numerous islands and remote locations, as well as ships at sea, which also could receive valuable information from a WEFAX system. With the addition of weather charts to the APT transmissions, thus enhancing their utility, many more nations could be expected to acquire APT sets.

3. FACTORS PERTINENT TO WEFAX TRANSMISSIONS FROM SUN-SYNCHRONOUS SATELLITES

As will very shortly be demonstrated, the factors which establish the potential capabilities or limitations of WEFAX transmissions from sun-synchronous satellites are principally those related to satellite orbit altitude. The intervals between APT pictures that can be made available for WEFAX transmissions increase with increasing orbit altitude, due to both the greater field of view of each APT picture and the slower orbit velocity. Furthermore, the ranges at which APT stations can receive data also increase with an increase in spacecraft altitude. Higher orbit altitudes are most beneficial relative to directions more or less parallel to the orbit track. In the cross track direction, both this benefit and the greater field of view of the camera are nearly neutralized by the greater longitudinal distances (except near the poles) between adjacent orbits.

3.1 Orbital Considerations

3.1.1 Assumptions

The sun-synchronous satellite is assumed to be of the Nimbus or TOS type,* in a quasi-polar circular orbit at an inclination of approximately 100 degrees to the earth's equatorial plane, with the precise inclination and orbit altitude appropriately coordinated.[7] It is assumed, also, that the APT camera has an 88.9 degree square field of view. Table 3-1 lists some characteristics of sun-synchronous orbits, and the widths on the earth of APT pictures, as functions of altitude. On the dayside of the orbit, weather chart transmissions (WEFAX) through the APT system are assumed to occur between APT picture transmissions, and to be so scheduled as to require minimum reduction in the coverage provided by the APT pictures. The time interval available for WEFAX (between the 208 seconds required to take, scan, and transmit an APT picture) is determined,for any orbit altitude, by the overlap desired between succeeding APT pictures. Once the desired overlap has been specified, it and the orbit altitude determine the frequency at which pictures must be taken, and so the time interval available for WEFAX transmissions.

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* For simplicity and clarity of discussions, most of this report has been prepared specifically in terms of the Nimbus case, with south-to-north daytime passes. It is obvious that, with simple inversions of the order of transmissions and other equally insignificant rearrangements, these results can easily be generalized to include the north-to-south daytime passes of an APT-equipped TOS.

3.1.2 APT Picture Coverage and Overlap, and Time Available for WEFAX

The number of APT pictures, N, required for full latitudinal coverage of the dayside portion of a circular orbit of period P, with no overlap, is:

$$N = {}^{180}/A$$

where A is the distance, in degrees of Great Circle Arc, covered by an APT picture.

For all practical purposes, a satellite in a circular orbit sweeps equal arcs on the earth's surface in equal time intervals. Therefore, the time interval, from the taking of one APT picture to the next, for the case of no overlap, is:

$$T_o = (P/2)/N$$

Of course, even for a very low orbit (or if a large overlap between successive pictures were for some reason to be desired), the time interval between successive pictures (such as T_o in the above equation), can never be less than C, the 208 second (3.5 minute) cycle time required to take, scan, and transmit an APT picture.

Assuming that WEFAX is not to be allowed to interfere with completely contiguous APT coverage, the time available for WEFAX, T_A, between APT pictures is, as a maximum:

$$T_A = T_o - C.$$

In general, it will be desirable to provide for some overlap between successive APT pictures to aid in mosaicing and in correcting for any significant yaw errors. Because of the essential proportionality between time along the orbit and distance along the earth, an increase in the precentage of overlap between succeeding pictures, L, approximately corresponds to an equal percentage decrease in the time interval between pictures, and the more general expression for the time available for WEFAX transmissions is:

$$T_A = T - C, \text{ where } T = T_o - \frac{T_o L}{100} \text{ and } T \geq C \text{ ; or } T_A = T_o\left(1 - \frac{L}{100}\right) - C$$

Table 3-2 and Figure 3-1 illustrate the relationships of T and T_A, as functions of both satellite height and percentage overlap between APT pictures. In addition, Table 3-2 presents the equivalent lengths of recorded WEFAX for each time available, T_A, between APT pictures. It is assumed that the paper advance speed of the facsimile is the same as for the APT picture, or 2.4 inches per minute (Fairchild Model).*

* All calculations in this report assume the Fairchild facsimile recorder, where the APT pictures are presented in an 8" x 8" format. For other recorders, the sizes of WEFAX presentations would be in the same ratio as their APT picture dimensions are to the Fairchild format.

Table 3-1

Some characteristics of sun-synchronous satellite orbits, and of APT camera coverage,for various typical altitudes

HEIGHT (n. miles)	PERIOD (minutes)	INCLINATION (degrees)	ASCENDING NODE INCREMENT (degrees long.)	APT SIDE COVERAGE (n.miles)	APT SIDE COVERAGE (degrees of Great Circle Arc)
500	103.1	98.9	25.8	1060	17.7
550	105.2	99.4	26.3	1180	19.7
600	107.4	99.9	26.8	1300	21.7
650	109.4	100.4	27.3	1420	23.7
700	111.4	100.8	27.8	1550	25.8
750	113.4	101.3	28.4	1680	28.0
800	115.4	101.7	28.7	1820	30.3
850	117.5	102.2	29.3	1960	32.7
900	119.6	102.7	29.9	2110	35.2
950	121.7	103.2	30.4	2260	37.7
1000	123.7	103.8	30.9	2420	40.3

Table 3-2

Relationships between the time intervals between APT pictures (T), the times available for WEFAX transmissions (T_A), and the equivalent lengths of recorded WEFAX presentations, as functions of satellite height and percentage overlap between APT pictures.

SATELLITE HEIGHT (n. miles)	NO OVERLAP			10% OVERLAP			25% OVERLAP		
	$T = T_o$ (minutes)	T_A (minutes)	WEFAX Length (inches)	T (minutes)	T_A (minutes)	WEFAX Length (inches)	T (minutes)	T_A (minutes)	WEFAX Length (inches)
500	5.2	1.7	4.1	4.7	1.2	2.9	3.9	.4	1.0
550	5.9	2.4	5.8	5.3	1.8	4.3	4.4	.9	2.2
600	6.6	3.1	7.4	5.9	2.4	5.8	4.9	1.4	3.4
650	7.3	3.8	9.1	6.5	3.0	7.2	5.5	2.0	4.8
700	8.0	4.5	10.8	7.2	3.7	8.9	6.0	2.5	6.0
750	8.8	5.3	12.7	8.0	4.5	10.8	6.6	3.1	7.4
800	9.6	6.1	14.6	8.8	5.3	12.7	7.3	3.8	9.1
850	10.5	7.0	16.8	9.6	6.1	14.6	8.0	4.5	10.8
900	11.6	8.1	19.4	10.4	6.9	16.6	8.7	5.2	12.5
950	12.7	9.2	22.1	11.4	7.9	19.0	9.5	6.0	14.4
1000	13.9	10.4	25.0	12.5	9.0	21.6	10.4	6.9	16.6

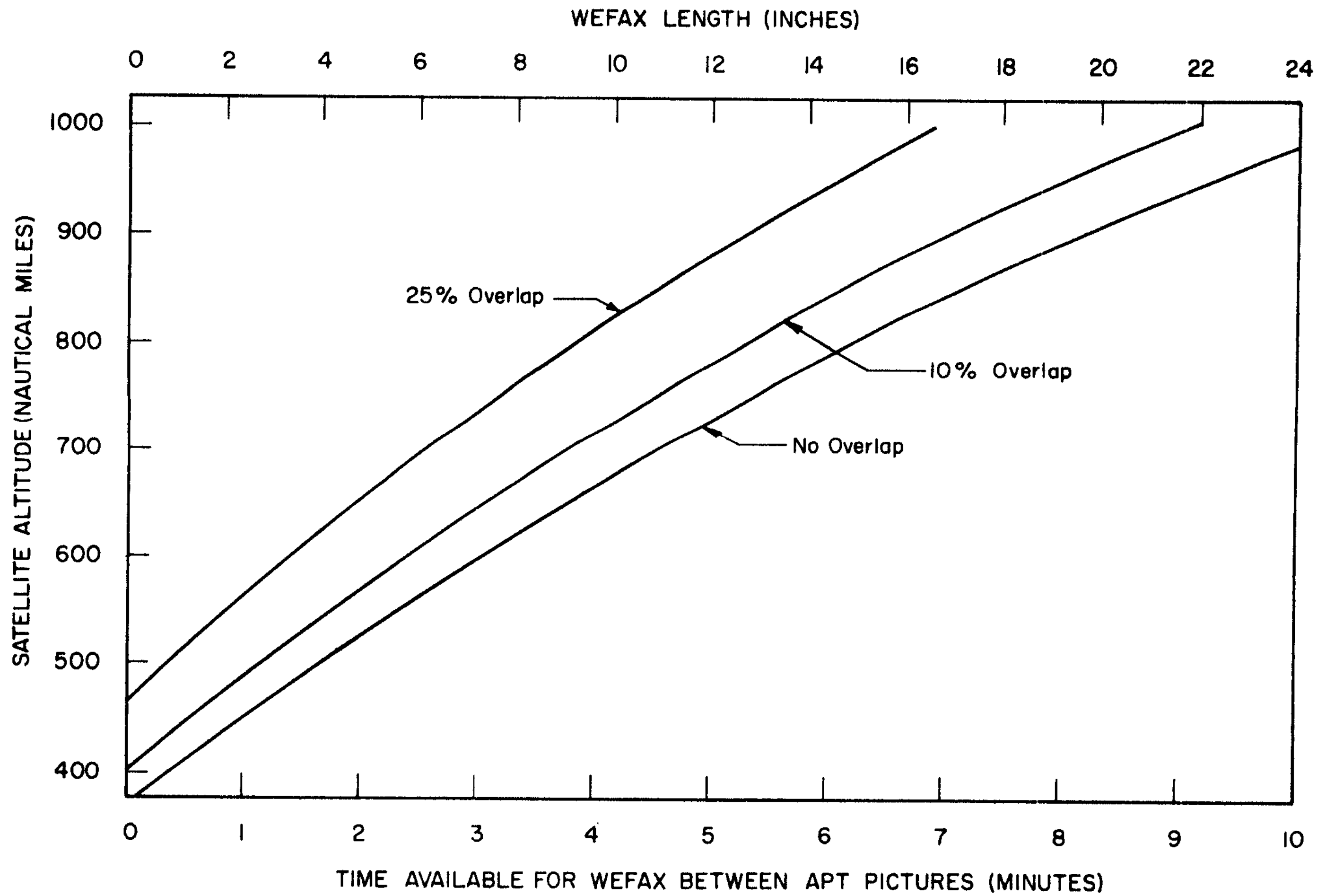

Figure 3-1 Time available between APT pictures for WEFAX transmissions as a function of satellite altitude and percentage area overlap between APT pictures.

It is evident that the time available for WEFAX transmissions, during daytime, and between APT pictures, increases with satellite height and decreases with increased percentage overlap between successive APT pictures.

3.1.3 Station Acquisition Times

The tracking time of a station during a single satellite pass determines the total length of APT pictures and WEFAX information that can be received. As is evident in Table 3-3, the maximum tracking time (the case of an overhead pass), and therefore the maximum length of facsimile record that can be received by a station, increase with satellite altitude. The maximum tracking times listed in Table 3-3 were calculated assuming a 10 degree minimum antenna elevation angle. (Hereafter, a 10 degree minimum antenna elevation angle will be used for all calculations.) Most passes will be of somewhat lesser duration (see the next section and Table 3-4).

3.1.4 Numbers of Passes Received

The total amount of WEFAX and APT that can be received is also determined by the number of passes that a station can acquire, on the average, on any day. The orbital tracks for satellites in quasi-polar orbits converge toward the poles; therefore, the numbers of passes that stations can acquire increase with the latitude of the station. Table 3-4 shows the average numbers of day passes, of at least 10 minutes duration, that can be acquired by stations at different latitudes, for satellites at 600, 750, and 1000 n.mi. altitude. Equal numbers of passes may also be acquired at night. The values in Table 3-4 were obtained by mapping the station acquisition ranges and satellite subpoint tracks for the three satellite altitudes. The numbers and the lengths of tracks crossing through the station acquisition circles were averaged for many pass configurations. The track lengths are readily convertible to acquisition times. Only passes lasting ten or more minutes were included in the averages. Again, a ten degree minimum antenna elevation angle was used for computing the acquisition ranges.

Table 3-3

Maximum tracking times, for case of an overhead pass and a 10 degree minimum antenna elevation angle

Satellite Height (nautical miles)	Maximum Tracking Time (minutes)
500	11.8
550	12.7
600	13.7
650	14.6
700	15.5
750	16.4
800	17.2
850	18.1
900	19.0
950	19.9
1000	20.7

Table 3-4

Average numbers of acquirable day passes, of ten or more minutes duration, for a 10 degree minimum antenna elevation angle.

Satellite Height (nautical miles)	Station Latitude (N/S)				Average Duration (minutes)	Facsimile Length (inches)
	0^{o}	20^{o}	40^{o}	60^{o}		
600	$1\frac{1}{2}$	$1\frac{1}{2}$	2	3	$12\frac{1}{2}$	30
750	$1\frac{1}{2}$	$1\frac{1}{2}+$	2+	4−	$14\frac{1}{2}$	35
1000	2−	2	$2\frac{1}{2}$	$4\frac{1}{2}$	$17\frac{1}{2}$	42

3.1.5 Orbital Conclusions

It is apparent from Tables 3-2 and 3-4 that, for maximum length of WEFAX transmissions during the dayside of the orbit, both small overlap between APT pictures and high orbit altitudes are desirable. A low orbit reduces both the number of passes per day that a station can acquire and their duration, while a large overlap, with more frequent APT transmissions, would reduce the transmission times available for WEFAX. It is therefore, highly desirable to reduce APT overlap to a near minimum while still insuring that contiguous APT coverage is transmitted to each acquiring station during any one pass, or any adjacent sequence of passes.

It will be shown that, for a sun-synchronous satellite at 750 n. mi. altitude (as planned for Nimbus D), a 10% overlap between APT pictures provides both adequate APT coverage and useful lengths of WEFAX transmissions to any station, regardless of its geographic location.

3.2 Detailed Consideration of the Case of a 750 Nautical Mile Orbit Altitude

For a 750 n. mi. satellite, a 10% overlap will occur if pictures are taken at 8.05 minute intervals (approximately one APT picture every 25 degrees of latitude) on the dayside of the orbit. This will, in turn, permit seven 8" x 11" (Fairchild facsimile recorder paper area) WEFAX transmissions every half orbit, or a total of 31 ½ minutes of WEFAX transmissions. For the cases of a 600 n. mi. orbit, or of a TOS satellite taking APT pictures every 352 seconds, only slightly more than one-half of this amount of WEFAX record would be available.* Analyses of the numbers and types of charts that can be transmitted for the 750 n. mi. cases, to be presented later in this report, will make it obvious that the amount of data that could be transmitted for the 600 n. mi. case would be patently inadequate. We have, therefore, concentrated our efforts on the formulation of WEFAX transmission formats and programs for a 750 n. mi. altitude satellite of the Nimbus type, and for the case of an earth-synchronous satellite (see Section 4).

Present NASA plans call for the WEFAX data to be transmitted to the satellite from a Nimbus Data Acquisition Facility (DAF) at a 32:1 satellite record to playback ratio. Assuming a nominal 10 minute contact time, the DAF has ample time to send to the satellite an amount of data equal to continuous WEFAX transmissions over

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* This statement does not preclude the later use, for WEFAX, of a 750 n. mi. TOS whose frequency of APT transmissions was redesigned to an interval of the order of eight minutes.

more than two full orbits. Accordingly, the WEFAX data can be transmitted for the next and one blind orbit, including no WEFAX data periods at intervals and of lengths appropriate to the intervening APT picture transmissions (i.e., 208 second WEFAX data blanks every 8.05 minutes of playback time).

3.2.1 Analysis of APT Picture Coverage

The area of coverage of an APT picture at a satellite altitude of 750 n.mi. is a "square" on the earth whose sides are about 1,680 n.mi. This section will analyze typical APT coverages that would be received by representative stations assuming a 750 n.mi. altitude satellite, a 10 degree minimum antenna elevation angle, and 10% overlap between APT pictures. For simplicity, we will assume that, in any one case analyzed, APT pictures are taken at the same latitudes on successive daylight passes, and will illustrate the acquisition potentials of stations at 20°N and 40°N for the following two extreme satellite pass configurations:

1. An overhead pass (including any usefully acquirable adjacent passes), and
2. Two successive passes, such that the station is located midway between the two subsatellite tracks.

To illustrate that the relative latitude of a station, compared to the latitudes of APT versus WEFAX transmissions, does not significantly influence the available APT coverage, we illustrate two latitudinal distributions of APT schedules:

1. An APT is always taken at the Ascending Node* (and each 8.05 minutes before and after), and
2. An APT is always taken at 208 seconds before Ascending Node (and each 8.05 minutes before and after this picture).

The pictures have the usual south to north scan-line sequence, aligning the eight inches on the facsimile approximately east to west. Figure 3-2 illustrates these APT and WEFAX transmission sequences.

A third latitudinal distribution, that for an APT picture taken 2.3 minutes after Ascending Node, was also analyzed. In this case, the latitudinal distributions of APT and WEFAX transmissions are intermediate between those for the two cases listed just above and shown in Figure 3-2. Since the APT coverages for this case were not significantly different from those for the other two, they have not been illustrated.

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* Ascending Node is the northbound equator crossing of the satellite.

3.2.1.1 Typical APT Coverages

The resulting APT coverages are shown in Figures 3-3, 3-4, 3-5, and 3-6; and in Table 3-5. For comparison, the southern and northern limits of the APT coverage obtainable, had the satellite transmitted an APT picture at the maximum possible rate of one every 208 seconds, are marked on the subsatellite tracks of each of the illustrations. The APT coverage lost is, in essentially all cases, too far away from the station to be of immediate practical use. The illustrations demonstrate the quantities and coverages of APT pictures that stations in middle and low latitudes can expect to receive on any one day, if WEFAX transmissions are also included; it is obvious that WEFAX data can be transmitted without loss of any APT data very likely to be significant to a station. Further north, stations will be able to receive a greater number of passes per day and the APT pictures will have substantial side to side overlap, perhaps providing somewhat better coverage. Near the equator, the APT coverage relative to a station will not differ substantially from that relative to a station at 20°N, since the average numbers and durations of daily passes are about the same. Since, as can be noted in Figure 3-2, the "at AN" transmission pattern north of the equator is a mirror image of the "208 seconds before AN" pattern south of the equator, and vice versa, these findings as to adequate APT coverage are equally valid for stations south of the equator. Thus, a 750 n.mi. sun-synchronous satellite orbit and a 10% overlap between APT pictures will permit the transmission of an 8" x 11" WEFAX area without sacrificing substantial APT coverage, regardless of station location. Accordingly, as stated above and because a 750 n.mi. orbit altitude is planned for Nimbus D, optimum WEFAX programs will be formulated mainly for this set of orbit and transmission parameters for the sun-synchronous case.* The earth-synchronous case is separately analyzed in Section 4.

3.2.1.2 High Latitude Reception

At higher latitudes, there will be increasing overlap between APT pictures from adjacent orbits. When this overlap exceeds 50%, high latitude APT pictures could, if necessary, be taken only every other orbit, without sacrificing fully contiguous coverage; those portions of the orbits where APT could be omitted could then be utilized to transmit WEFAX. This scheme would, however, sacrifice some

* It is obvious from the preceding analysis that even greater quantities of WEFAX could be transmitted, without endangering adequate and contiguous APT coverage, for higher orbit altitudes.

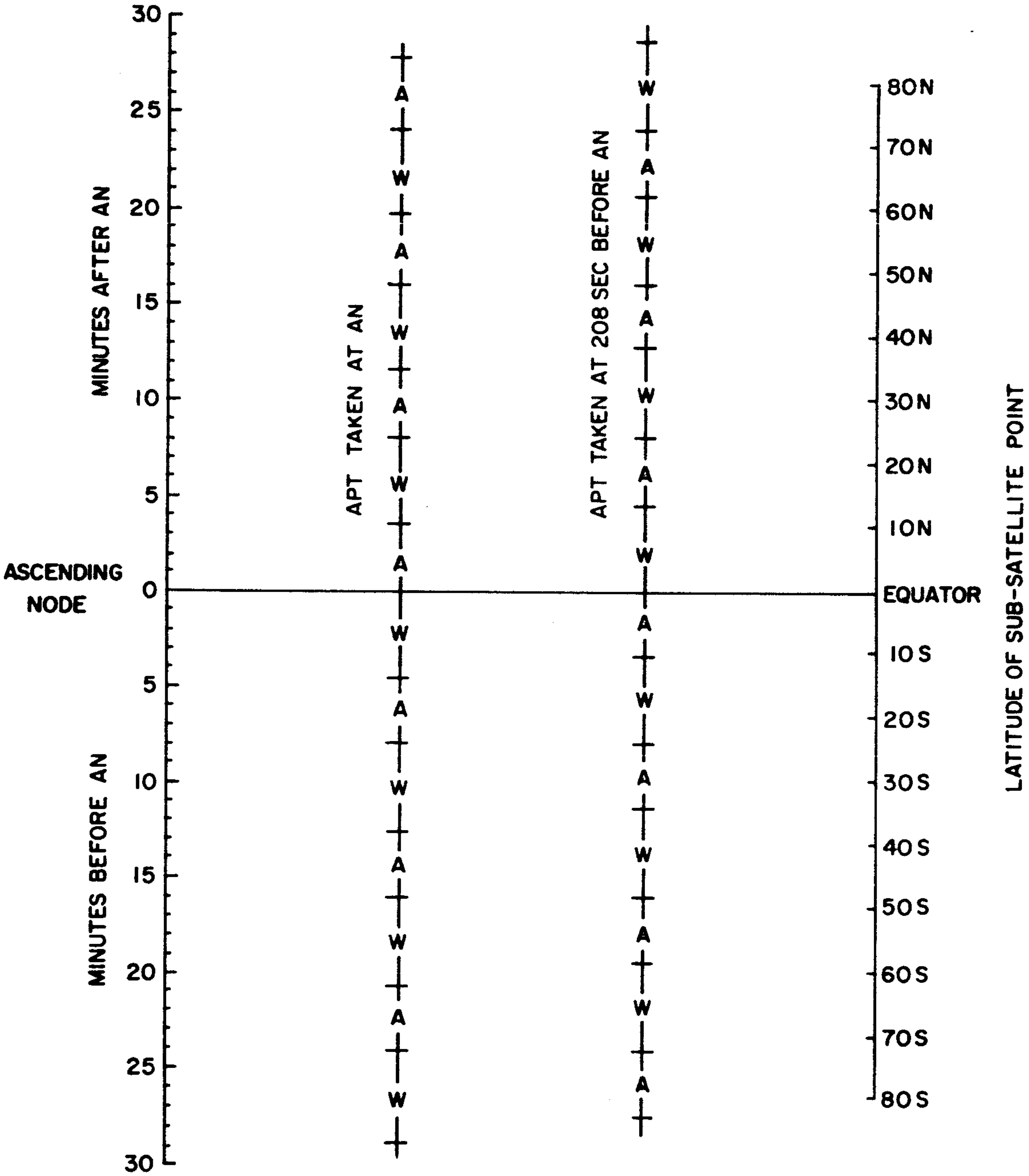


Figure 3-2 Two Possible APT and WEFAX Sequences for a 750 Nautical Mile Orbit and 10% Overlap Between APT Pictures.

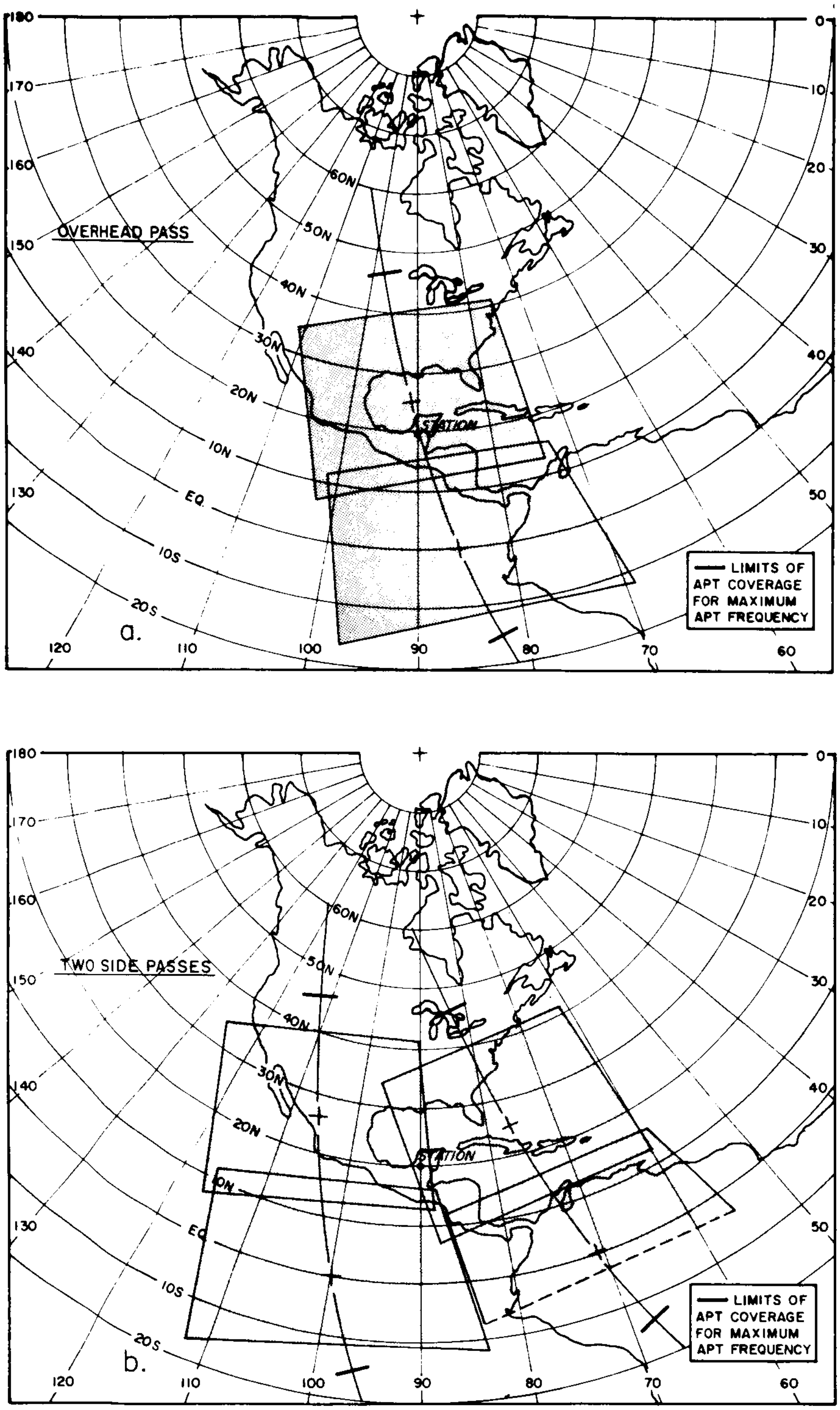


Figure 3-3 APT coverage for a station at 20N. An APT is taken at Ascending Node and 8.05 minute intervals on dayside of orbit. Satellite height is 750 nautical miles. 10% overlap between APT pictures.

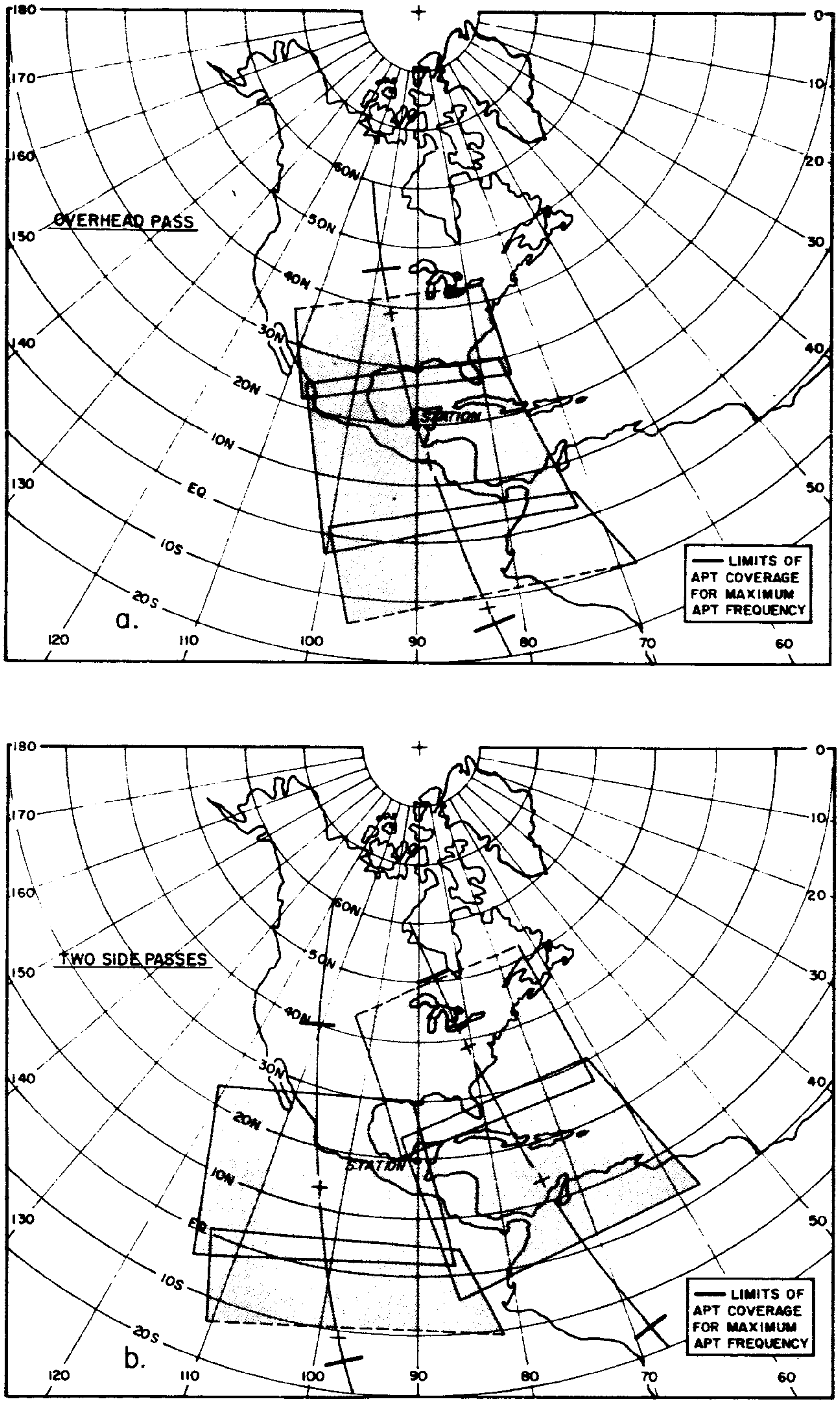
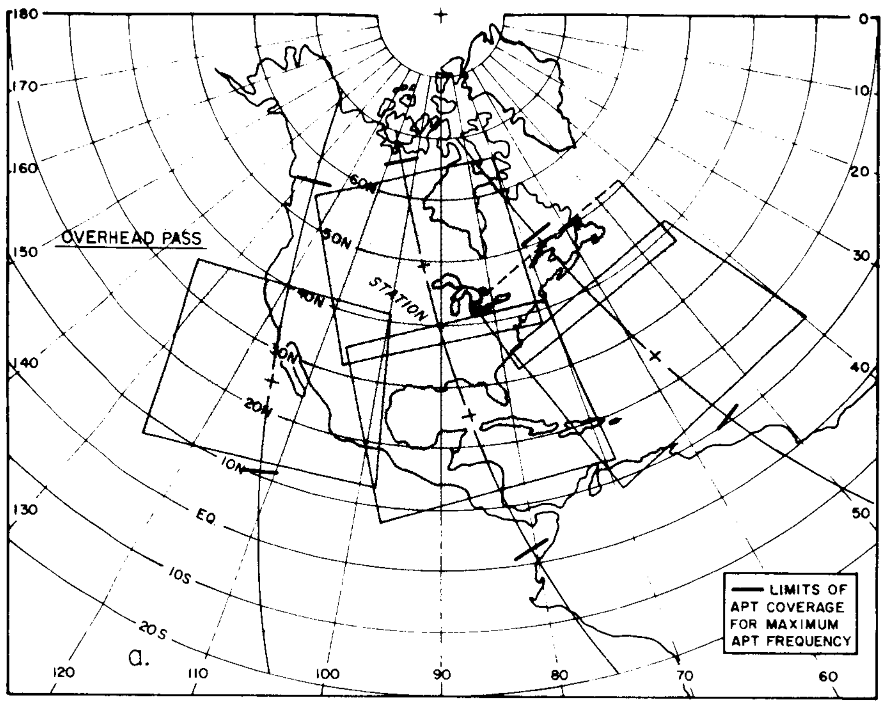


Figure 3-4 APT coverage for a station at 20N. An APT is taken at 208 seconds before Ascending Node and at 8.05 minute intervals on dayside of orbit. Satellite height is 750 nautical miles. 10% overlap between APT pictures.



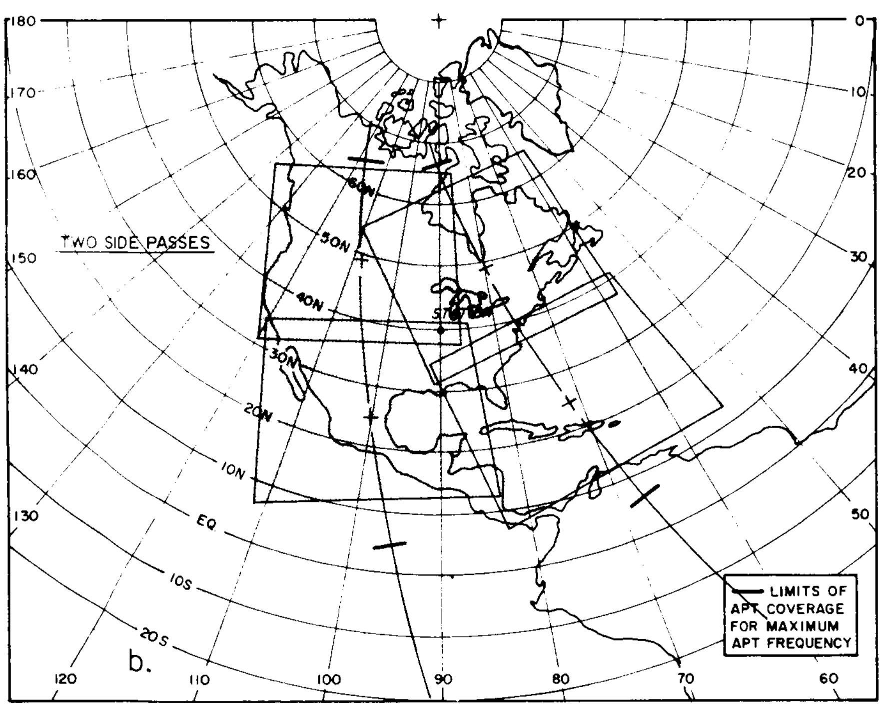


Figure 3-5 APT coverage for a station at 40N. An APT is taken at Ascending Node and at 8.05 minute intervals on dayside of orbit. Satellite height is 750 nautical miles. 10% overlap between APT pictures.

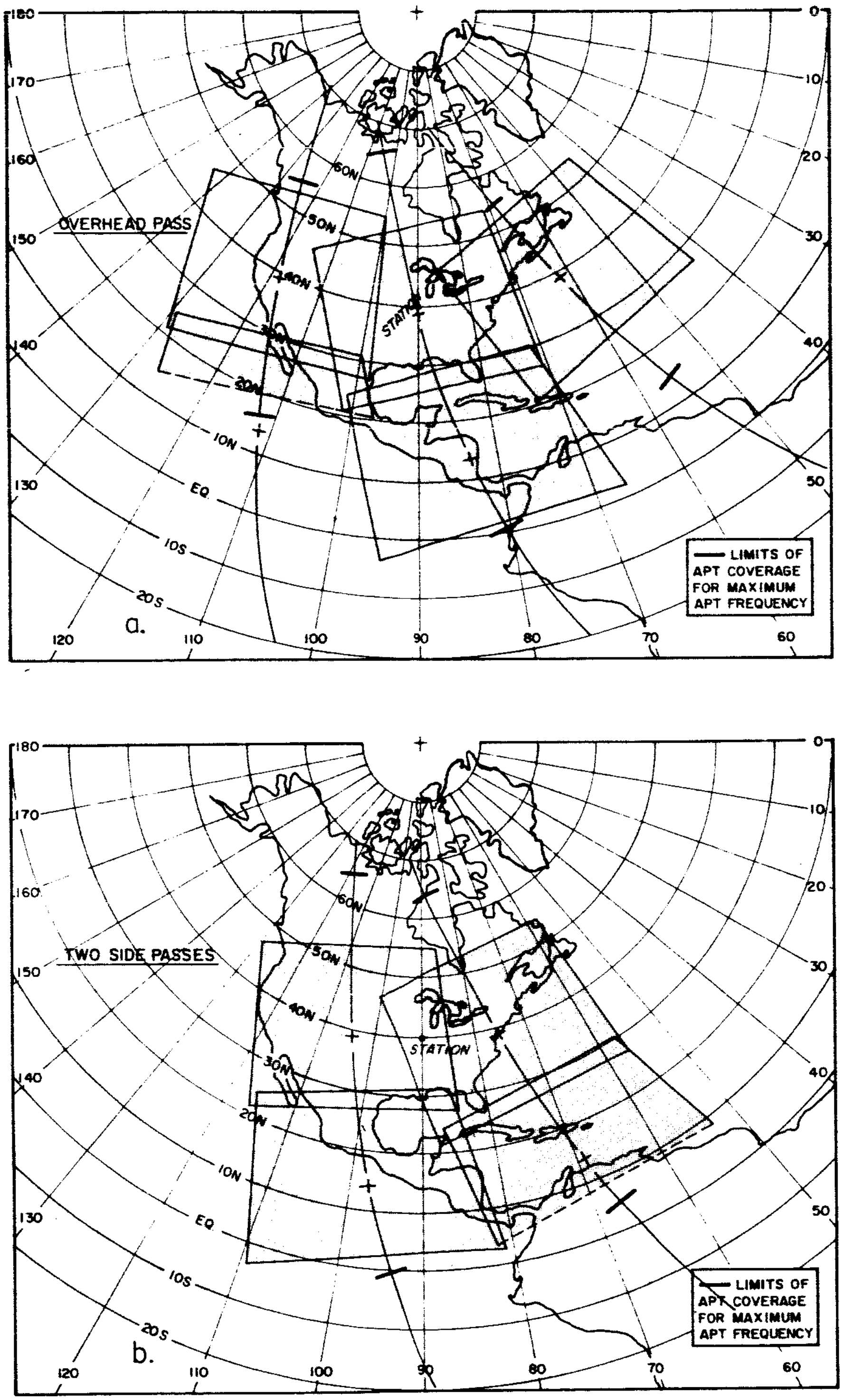


Figure 3-6 APT coverage for a station at 40N. An APT is taken at 208 seconds before Ascending Node and at 8.05 minute intervals on dayside of orbit. Satellite height is 750 nautical miles. 10% overlap between APT pictures.

Table 3-5

Station Acquisition Examples

This table presents the 8" x 8" APT pictures, and the 8" x 11" WEFAX transmissions,* that can be acquired, by stations at 20°N and 40°N, from a sun-synchronous satellite at 750 n.mi. altitude, assuming 10% overlap between APT pictures and a 10 degree minimum antenna elevation angle.

STATION AT 20°NORTH

1. An APT is assumed to be taken at the Ascending Node

   a) An overhead pass (of 16 minutes) will provide the following acquisition sequence:

$\frac{1}{3}$ -	WEFAX**	
1	APT	centered at equator
1	WEFAX	
1	APT	centered at 25°N
$\frac{2}{3}$ +	WEFAX	

   Little or no data are acquired on the side passes.

   b) Two side passes - subsatellite tracks equidistant from station. Both passes last approximately $14\frac{1}{2}$ minutes.

   Acquisition sequence is:

First pass	$\frac{2}{3}$	APT	centered at equator
	1	WEFAX	
	1	APT	centered at 25°N
	$\frac{2}{3}$	WEFAX	
Second pass	$\frac{1}{4}$	WEFAX	
	1	APT	centered at equator
	1	WEFAX	
	1	APT	centered at 25°N
	$\frac{1}{3}$	WEFAX	

Figure 3-3 illustrates the APT coverages that can be received.

---

* A Fairchild facsimile recorder is assumed.

** This notation indicates that slightly less than $\frac{1}{3}$ of an 8" x 11" WEFAX transmission (say, about an 8" x $3\frac{1}{2}$" transmission) will be received. The acquirable WEFAX transmissions for typical stations have not been included in Figures 3-3 through 3-6 (which are designed to demonstrate APT coverage and contiguity), but will be discussed and illustrated in Section 3.4 and Figures 3-13 through 3-18.

STATION AT 20°NORTH (cont)

2. An APT is assumed to be always taken at 208 seconds before Ascending Node.
   a) An overhead pass (of 16½ minutes) will provide the following acquisition sequence:

½	APT	centered at 11°S
1	WEFAX	
1	APT	centered at 14°N
1	WEFAX	
⅔	APT	centered at 39°N

   Little or no data are acquired on side passes.

   b) Two side passes - subsatellite tracks equidistant from station. Both passes last approximately 14½ minutes.

   Acquisition sequence is:

First pass	½+	WEFAX	
	1	APT	centered at 14°N
	1	WEFAX	
	1-	APT	centered at 39°N
Second pass	½	APT	centered at 11°S
	1	WEFAX	
	1	APT	centered at 14°N
	1	WEFAX	

Figure 3-4 illustrates the APT coverages that can be received.

STATION AT 40° NORTH

1. An APT is assumed to be always taken at the equator.

   a) An overhead pass (of $16\frac{1}{2}$) minutes will provide the following acquisition sequence:

$\frac{1}{2}$+	WEFAX	
1	APT	centered at 25°N
1	WEFAX	
1	APT	centered at 49.5°N
$\frac{1}{3}$	WEFAX	

In addition, the station will be able to track the pass before and the pass after the overhead pass, each for about 10 minutes. These passes would provide:

Preceding pass	1	APT	centered at 25°N
	1	WEFAX	
	$\frac{1}{2}$	APT	centered at 49.5°N
Following pass	$\frac{1}{3}$	WEFAX	
	1	APT	centered at 25°N
	1	WEFAX	

   b) Two side passes - subsatellite tracks equidistant from station. Both passes last approximately $14\frac{1}{2}$ minutes.

   Acquisition sequence is:

First pass	$\frac{1}{2}$-	WEFAX	
	1	APT	centered at 25°N
	1	WEFAX	
	1	APT	centered at 49.5°N
	$\frac{1}{3}$	WEFAX	
Second pass	$\frac{2}{3}$	WEFAX	
	1	APT	centered at 25°N
	1	WEFAX	
	1	APT	centered at 49.5°N

Figure 3-5 illustrates the APT coverages that can be received.

STATION AT 40°NORTH (cont)

2. An APT is assumed to be always taken at 208 seconds before equator crossing.

a) An overhead pass (of 16½ minutes) will provide the following acquisition sequence:

1	APT	centered at 14°N
1	WEFAX	
1	APT	centered at 39°N
1	WEFAX	

In addition, the station will be able to track the pass before and the pass after the overhead pass, each for about 10 minutes. These passes would provide:

Preceding pass	1	WEFAX	
	1	APT	centered at 39°N
	½	WEFAX	
Following pass	⅓	APT	centered at 14°N
	1	WEFAX	
	1	APT	centered at 39°N

b) Two side passes - subsatellite tracks equidistant from station. Both passes last approximately 14½ minutes.

Acquisition sequence is:

First pass	⅔	APT	centered at 14°N
	1	WEFAX	
	1	APT	centered at 39°N
	1	WEFAX	
Second pass	1	APT	centered at 14°N
	1	WEFAX	
	1	APT	centered at 39°N
	⅔	WEFAX	

Figure 3-6 illustrates the APT coverages that can be received.

of the meteorological information in the APT pictures in order to provide increased WEFAX transmission times. The lost information would be the cloud movements and developments over periods of approximately two hours, which may be very significant in mesoscale analysis. An APT overlap, between adjacent orbits, of 50% or more occurs poleward of approximately 66°N (or S) for a 600 n.mi. orbit, and of approximately 60°N (or S) for a 750 n.mi. orbit. For a 600 n.mi. orbit, the equatorward limit of 50% overlap is too far poleward to merit further consideration, especially in view of the previous elimination of this orbit (see Section 3.2). Accordingly, the analysis can be limited to the 750 n.mi. orbit, and, due to symmetry, to the Northern Hemisphere. At and poleward of 60°N, the satellite could be transmitting only WEFAX, through the APT system, on at least every alternate orbit. At the beginning of such transmissions, WEFAX could in principle be acquired by stations as far equatorward as 34 degrees, if the station is near the sub-satellite track. However, since the satellite is moving away from these lower latitude stations, acquisition time is negligible. Acquisition time increases northward, though, reaching a maximum near the Pole. The acquisition times at various latitudes are listed in Table 3-6. As Table 3-6 clearly shows, only stations at high latitudes (poleward of 45-50°) would benefit significantly, and stations at these latitudes are already favored by a relatively large number of passes per day (as the right column in Table 3-6 shows). This increase in acquirable orbits can, by itself, provide WEFAX transmission times in polar areas which are adequate and far in excess of those available at lower latitudes. Considering this, the loss in mesoscale APT information, and the increasing WEFAX programming complexity, the use of alternate poleward dayside portions of orbits for solely WEFAX transmissions does not appear to be merited and will not be further considered.

3.2.2 WEFAX Transmissions at Night

Current plans call for the use of the APT system to transmit HRIR data at night (DRIR). The design of the HRIR system makes it mandatory that these transmissions be continuous, unless gaps in the data are to be tolerated. Accordingly, the concept of alternate transmissions of WEFAX and other data, applied above to the APT case, is not applicable to the DRIR case. Since, however, for ease of satellite sensor-recorder synchronization, DRIR will occupy only about one-third of the width of the facsimile recorder paper, it was originally thought that the other two-thirds could be used to record significant amounts of WEFAX data. In order, however, to provide a facsimile

Table 3-6

Acquisition times that could be available exclusively for WEFAX dayside transmissions, for mid-latitude and polar stations. It is assumed that WEFAX is transmitted exclusively on every other orbit poleward of the latitude where APT pictures overlap by 50% or more from one orbit to the next. The data are for a 750 n.mi. sun-synchronous orbit.

STATION LATITUDE (degrees)	MAXIMUM ACQUISITION TIME Per Orbit (minutes)*	WEFAX Per Orbit (inches)	AVERAGE ACQUISITION TIME Per Orbit (minutes)*	WEFAX Per Orbit (inches)	NUMBER OF ORBITS**
34	≈ 0	≈ 0	≈ 0	≈ 0	≈ 2
40	1.6	3.8	1.3	3.1	2½
45	3.1	7.5	2.6	6.2	2½
50	4.7	11.3	4.0	9.6	3
60	8.2	19.7	7.0	17	4-
70	12.9	31.0	11.0	26.4	6

* Maximum acquisition times occur when stations are near the sub-satellite track. Average acquisition times are approximately 14/16.4 of maximum times (14.0 is average acquisition time for a 750 n.mi. orbit at 60°N, 16.4 is maximum acquisition time for a 750 n.mi. orbit.)

** AVERAGE NUMBER OF ACQUIRABLE DAYSIDE ORBITS PER DAY

Since continuous WEFAX transmission poleward of 60° could occur only every other orbit (without sacrifice of APT contiguity), the average number of orbits acquired on this mode would be half the number of orbits acquired per day. The numbers of orbits given are specifically for conditions near the equinoxes. In polar latitudes, they would be greater in local summer and less in local winter.

recorded aspect ratio compatible with the HRIR scan rate of 44.7 RPM, the rate of recorder paper feed must be reduced (either by means of a two speed motor, or a gear box assembly) from the APT rate of 240 lines per minute to a DRIR rate of 44.7 lines per minute. The area available for WEFAX will then be drastically curtailed (by a factor of about 5½ in length alone, compared to the APT rate) by the decreased speed of the facsimile drive necessary to accommodate the DRIR cycle rate. For example, a pass of average duration (14½ minutes) would produce only a 5" x 6½" WEFAX area, in addition to the 3" x 6½" DRIR strip. The use of the APT channel for simultaneous, side-by-side transmissions of DRIR and WEFAX, at night, does not, therefore, seem justifiable when viewed in terms of the combination of the limited amount of WEFAX area actually obtainable and the relatively complex satellite system modifications that would be required.

In the absence of DRIR, the APT system can, of course, be used to transmit WEFAX exclusively during the entire night portion of the orbit. In this case, an average pass of 14½ minutes (for a 750 n.mi. altitude satellite), would produce 35 inches of WEFAX. Since it is expected that DRIR will be the primary nocturnal mode of APT, the transmission of WEFAX at night, when permitted, should be programmed solely as a supplement to the basic weather charts transmitted, during daytime, in-between APT pictures. Nighttime WEFAX transmissions cannot be relied upon, nor can nighttime transmission be assumed when demonstrating that WEFAX can provide a useful number and variety of weather charts. Accordingly, nighttime WEFAX transmissions are not considered in the remainder of these analyses.

3.2.3 Conclusions with Regard to Transmission Factors

An analysis of the various factors, so far considered, which determine feasible WEFAX transmission programs through the APT system of a sun-synchronous satellite, has led to the following two main conclusions. These conclusions will guide the formulation of optimum programs:

1. A minimum of a 750 n.mi. satellite altitude and a minimum of a 10% overlap between APT pictures are desirable. For the specific case of the 750 n.mi. orbit and of a 10% overlap, which, as discussed previously, have been used for program formulation in this study, transmissions of 8" x 11" of recorded WEFAX area can be provided between successive APT pictures.

2. Assuming, as seems most reasonable, that the use of the DRIR becomes the standard mode of nighttime operation, the principal transmissions of WEFAX will occur during daytime.

In a reasonable study of the type undertaken here, it is obviously not feasible to fully consider the complete ranges of parameter variations that are possible. For this reason, we have already constrained our further analyses to the case of the 750 n.mi. orbit, and to a 10% APT picture overlap. For similar reasons, we must from hereon further constrain our analyses to specific latitudinal locations and sequences of the APT pictures.

For the purpose of developing specific programs, it will be assumed that an APT picture is always taken exactly at the equator. This constraint will distribute the other six possible APT pictures evenly among the two hemispheres, and will permit three 8" x 11" WEFAX transmissions in the northern hemisphere, and three or four in the southern hemisphere.

It is to be noted, however, that uniformly shifting the positions along the orbit of the APT pictures would not invalidate the general aspects or the general feasibility of the programs to be proposed. From the examples of APT coverages based on the two sequences presented in Figure 3-2 and discussed in Section 3.2.1, it is evident that, despite any shift of picture locations, adequate APT coverage will still be provided to all stations. Furthermore, regardless of any such shifts, at least three WEFAX transmission will always occur in each hemisphere (again see Figure 3-2). This study has led to the recommendation, as will be discussed in Section 3.3, that the transmissions for each hemisphere (on each orbit) consist of three latitudinally overlapping charts. This leads to programs whereby each of the WEFAX transmissions occurs approximately within the latitudinal boundaries of the chart being transmitted, regardless of the precise latitude over which APT pictures are transmitted. Accordingly, all stations will receive charts covering at least their primary areas of interest.

3.3 Base Map Selection

When selecting a system of operational weather charts, it is extremely desirable to adopt not only fixed chart scales, but also fixed geographical boundaries. It would be very unfortunate if the specific boundaries of the charts were to change constantly from day to day with the daily variations of the subpoint track of the satellite. (The somewhat analogous random shifts of the areas observed are believed to be one reason why the operational use of TIROS data has at times been less than would be expected.) Only when the chart areas are constant can vital day-to-day comparisons most readily be made.

The standard map projections for meteorological charts are now, with only rare exceptions, the polar stereographic for middle and high latitudes, and the Mercator for the tropical regions.

The scales of the various charts have been determined mainly by the dimensions, when facsimile recorded, of feasible WEFAX transmissions, and by the geographical coverages necessary to meet the needs of the receiving weather stations. While the desired geographical coverages will vary somewhat with the operational missions of stations, in middle and polar latitudes a normal synoptic chart will encompass about 40° of latitude by 90° of longitude, or slightly under 10,000,000 square miles. Ideally, the using station would be located near the middle latitude of the chart, and about 20-30° west of the eastern edge of the chart. In the tropics, a similar area should normally be encompassed, but the station should tend to the west, rather than to the east, of the center of the chart. While no reasonable WEFAX program could provide single charts directly meeting the requirements of all stations, those individual charts that are transmitted should, in so far as possible, cover geographical areas large enough to meet the needs of at least those stations in fortunate locations. Other stations must meet their needs by joint use of two or more charts (see Section 3.4).

As a further consideration, it is highly desirable, in so far as possible, to conform to map scales presently in use at the National Meteorological Center, Suitland, Maryland. These various considerations have led to the selection of the 1:30 million scale for the polar stereographic projection; and of the 1:40 million scale for the Mercator projection.

3.3.1 General Considerations

The 8" x 11" provided by a single WEFAX transmission (hereafter referred to as a WEFAX frame) could be used for one or more weather charts. The sequence of scan lines, relative to the chart coordinates, might be south-to-north, east-to-west, or west-to-east.* Since most weather systems move with a longitudinal component

* A north-to-south scan is obviously disadvantageous on a south-to-north pass, since the charts are then generated in a sense directly opposite to that of the satellite travel.

greater than their latitudinal component of translation, the longer dimension of the weather chart should be in the longitudinal (east-west) direction. Combinations of one, two, or four weather charts in an 8" x 11" WEFAX frame, and of various scanning modes have been considered.

Analyses have shown that a south-to-north scan line sequence is greatly to be preferred. This maximizes the probability of a station obtaining data for those latitudes nearest to it, and any partial charts received would in all probability be usable.

With this scan pattern, the division of each WEFAX frame into two 8" x $5\frac{1}{2}$" maps, with the alignment of the 8" dimension approximately east-west, is indicated by the desired longitude-latitude aspect ratio. Analyses have shown such a frame division to be entirely compatible with both acceptable scales (see Section 3.3) and charts of adequate geographical extent.*

3.3.2 Latitudinal Considerations

Following an analysis of optimum latitudinal coverages, it was determined that, for each orbit and each hemisphere, there should be a near polar chart, a mid-latitude chart, and a tropical chart. Charts covering the following latitudinal spans were found to be compatible with the projections and scales stated above (see Sections 3.3 and 3.3.1) and included in the following tabulation:*

Area	Projection	Scale	Latitude of Center Point	Latitude Span at Center Point
Polar	Polar stereographic	1:30 million	70°	51° to 90° (39°)
Mid-Latitude	Polar stereographic	1:30 million	42°	26° to 60° (34°)
Tropical	Mercator	1:40 million	11°	16°(S/N) to 36°(N/S) (52°)

The latitudinal spans of these six charts (three in each hemisphere) provide full latitudinal coverage and adequate latitudinal overlap, as can be seen in Figure 3-7. (The alphanumeric chart designators will be explained in Section 3.3.4.) It is

* It must be realized that the final selection of chart scales, facsimile areas, and geographical areas was based on a series of reiterated empirical trials, adjustments, and compromises which it would be pointless to recapitulate here.

significant that the latitudinal spans of the individual charts are typical of standard weather charts and that, for many station locations, a single chart will provide adequate coverage. It is further to be noted that (as will become more apparent in Section 3.4, when chart reception patterns of typical stations are demonstrated) there would be no gain from further latitudinal subdivision of the charts. This is fortunate, since it eliminates the need for reassemblies of small portions of larger charts by the receiving stations, which might well lead to minimal use of the WEFAX-transmitted data.

3.3.3 Longitudinal Considerations

From the longitudinal viewpoint, it first appeared that six tropical charts (for each hemisphere), six mid-latitude charts (in each hemisphere), and three polar or near-polar charts (in each hemisphere) would provide adequate coverage and overlap. Further analysis of various applicable factors led to the following three chief alternatives, each of which has its own short-comings, especially as regards the mid-latitude charts but also for the tropical charts:

1. Six charts (8" x 5½"), each of about 70° in longitude. This arrangement produces six 10-20° longitudinal "gaps", near the edges of the chart areas, where stations would often receive inadequate coverage to either their east or west.

2. Twelve charts* (8" x 5½"), each of about 70° in longitude. This arrangement results in large areas of overlap, which inherently leads to redundancy of transmitted information and to restrictions in the number of different types of charts that can be transmitted.

3. Twelve charts (4" x 5½"), each of about 35° in longitude. This arrangement, while optimum as regards minimum redundancy and maximum chart variety, would require stations to paste together chart segments, received on successive orbits, in order to obtain adequate coverage. This would probably lead to many stations deciding that the effort involved was too great as compared to the benefit gained. (Although this is obviously a short-sighted viewpoint, these tendencies have been frequently observed among operational forecasters.)

After due consideration of the many variables and of the shortcomings of each, the second alternative (12 overlapping, approximately 70° charts) appears to be the best and is that discussed hereafter. It provides at least minimally adequate

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* The use of twelve charts is as closely compatible as is feasible with the 12.7 orbits per day completed by a 750 n.mi. altitude satellite.

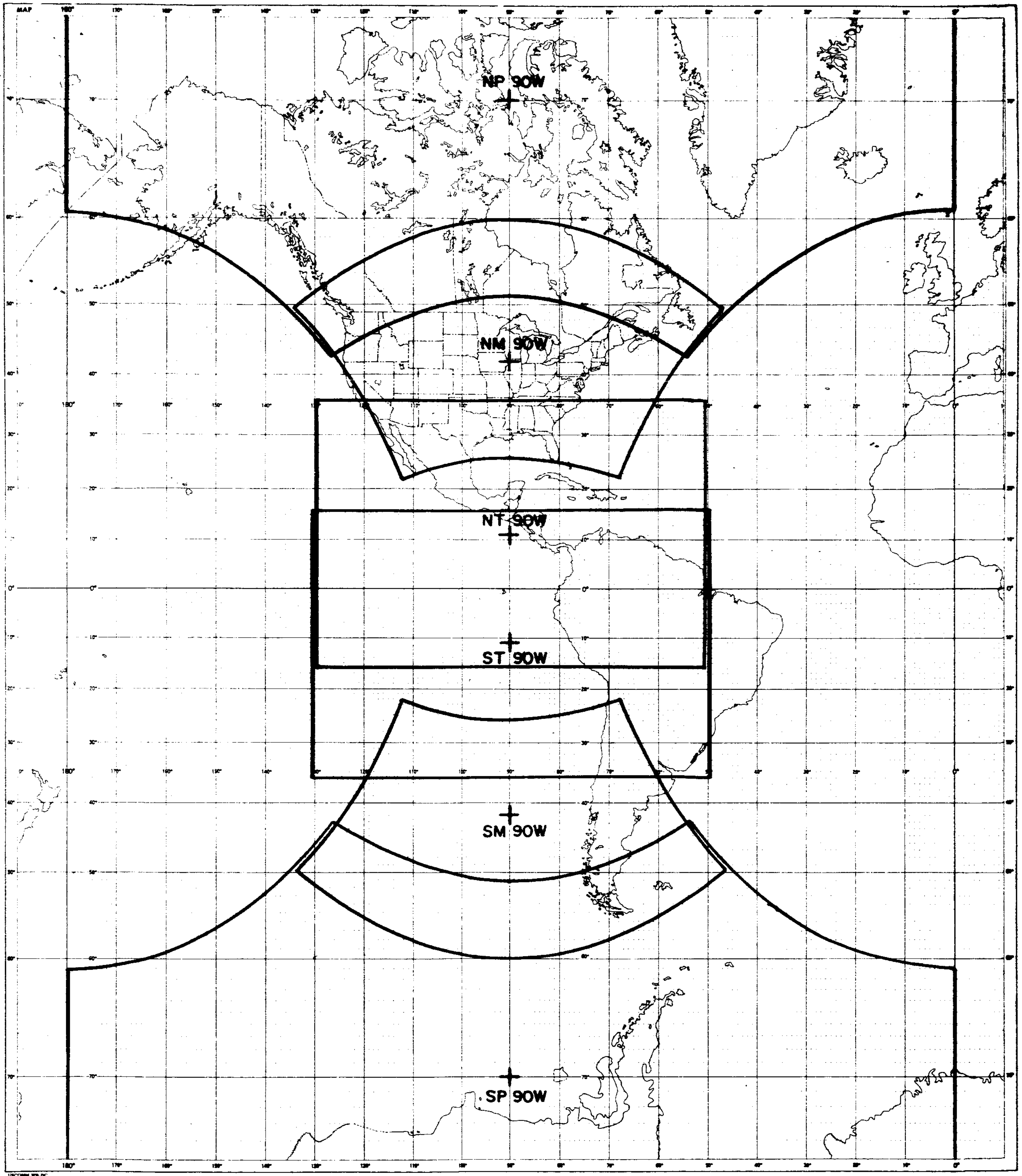

Figure 3-7 Latitudinal Coverages and Overlap of WEFAX Charts Proposed for Sun-synchronous Satellite Transmission.

information to all areas, and in a directly usable format. After forecasters come to depend on WEFAX data, the more sophisticated pattern of twelve charts each about 35° in longitude, which permits transmission of a greater variety of charts, might well be reconsidered.

3.3.4 Chart Areas Selected

Figures 3-8 through 3-12 depict the arrangement, areal coverage, longitudinal overlap, and chart numbers of the WEFAX chart areas (or base maps) recommended for sun-synchronous satellite transmission. Identification numbers have been assigned to each base chart. Each chart number is made up of two letters (a latitude reference), followed by the longitude of the center point of the chart. These chart numbers are listed in Table 3-7.

Table 3-7

Sun-Synchronous WEFAX Chart Numbers

NORTHERN HEMISPHERE			SOUTHERN HEMISPHERE		
Polar	Mid-Latitude	Tropical	Tropical	Mid-Latitude	Polar
Polar stereographic 1:30 Million	Polar stereographic 1:30 Million	Mercator 1:40 Million	Mercator 1:40 Million	Polar stereographic 1:30 Million	Polar stereographic 1:30 Million
NP0	NM0	NT0	ST0	NM0	SP0
	NM30E	NT30E	ST30E	NM30E	
NP60E	NM60E	NT60E	ST60E	NM60E	SP60E
	NM90E	NT90E	ST90E	NM90E	
NP120E	NM120E	NT120E	ST120E	NM120E	SP120E
	NM150E	NT150E	ST150E	NM150E	
NP180	NM180	NT180	ST180	NM180	SP180
	NM150W	NT150W	ST150W	NM150W	
NP120W	NM120W	NT120W	ST120W	NM120W	SP120W
	NM90W	NT90W	ST90W	NM90W	
NP60W	NM60W	NT60W	ST60W	NM60W	SP60W
	NM30W	NT30W	ST30W	NM30W	

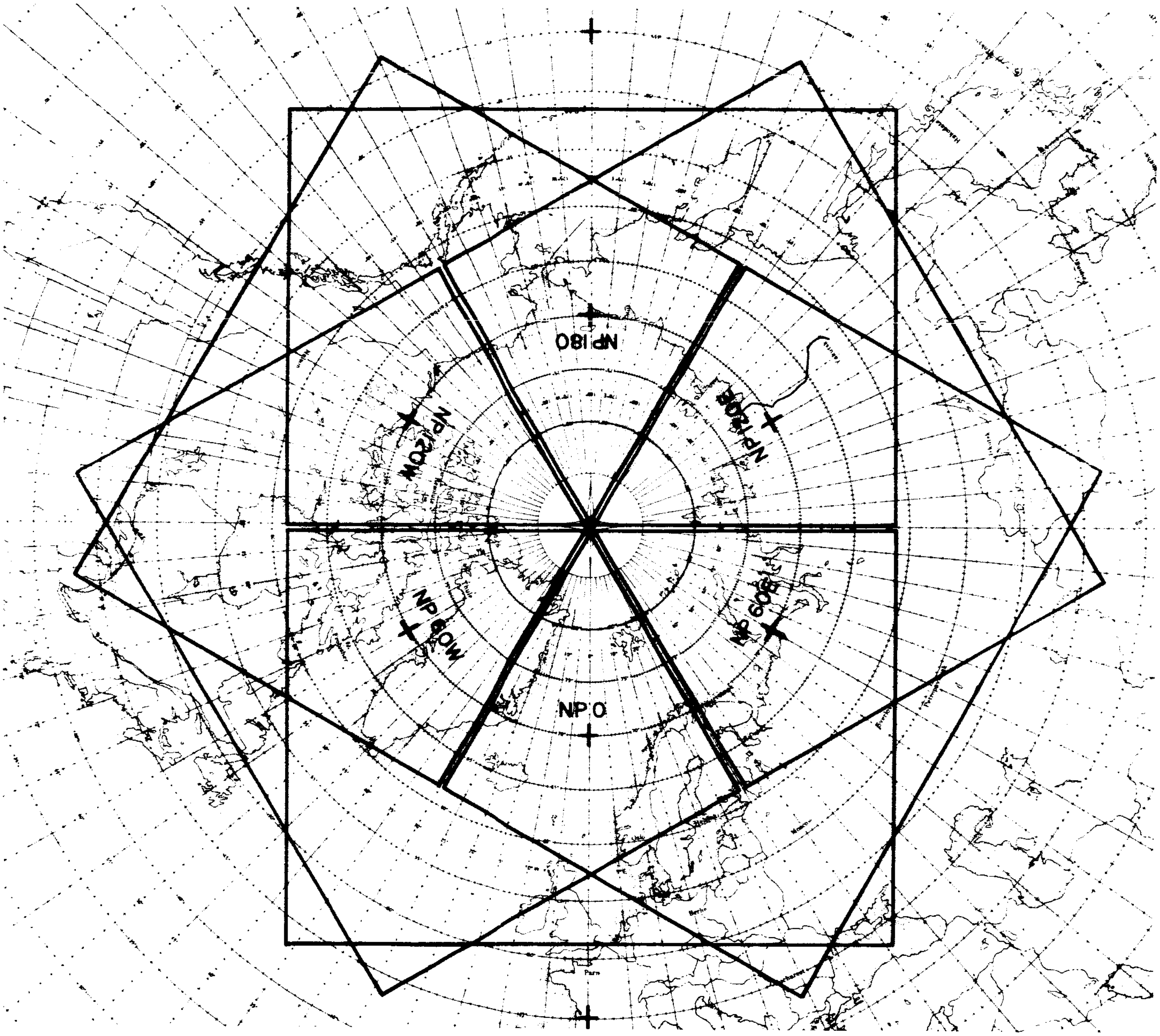

Figure 3-8 Northern Polar WEFAX Charts (6) For Sun-Synchronous Transmission.

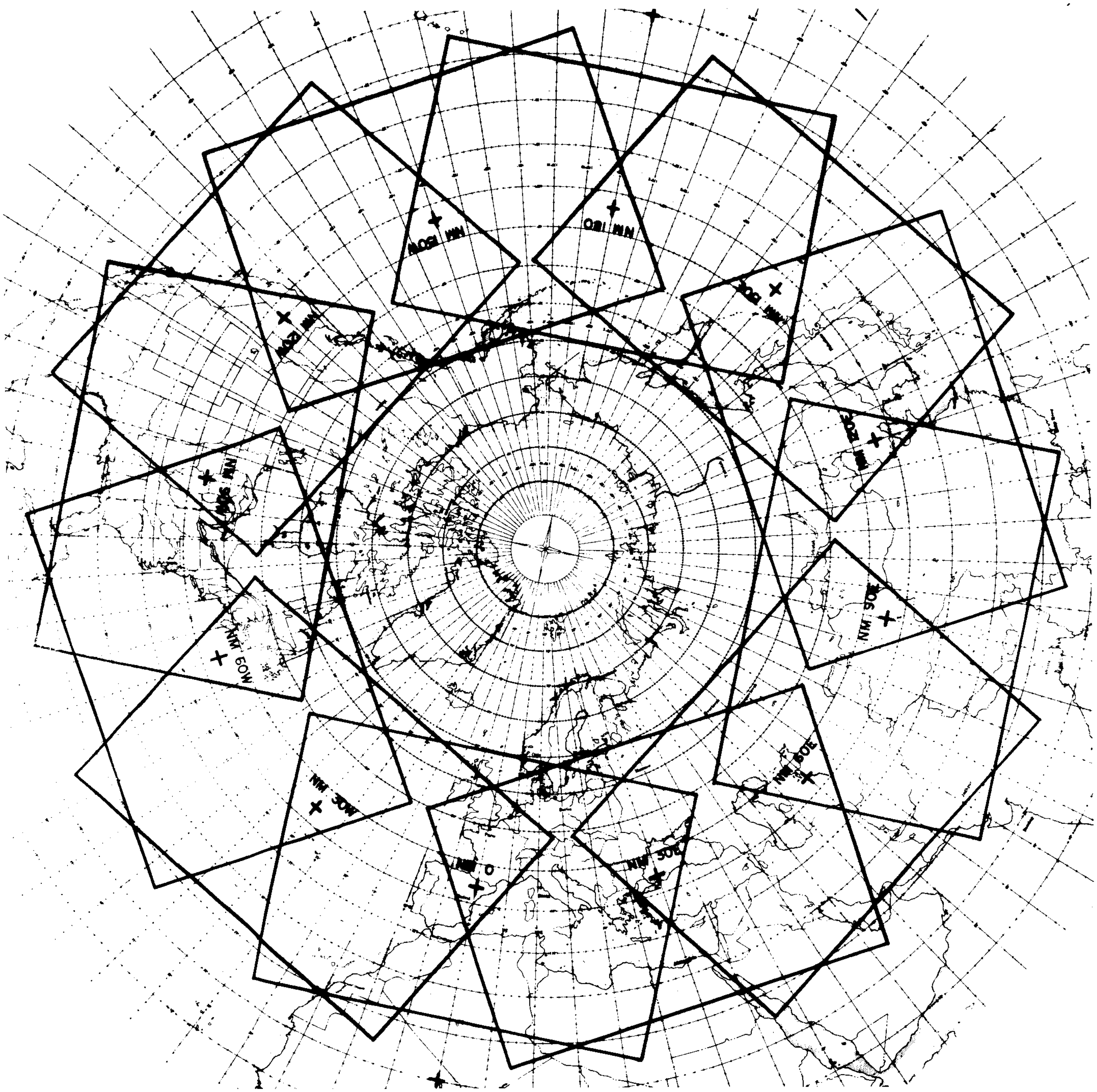

Figure 3-9 Northern Mid-Latitude WEFAX Charts (12) for Sun-synchronous Transmission

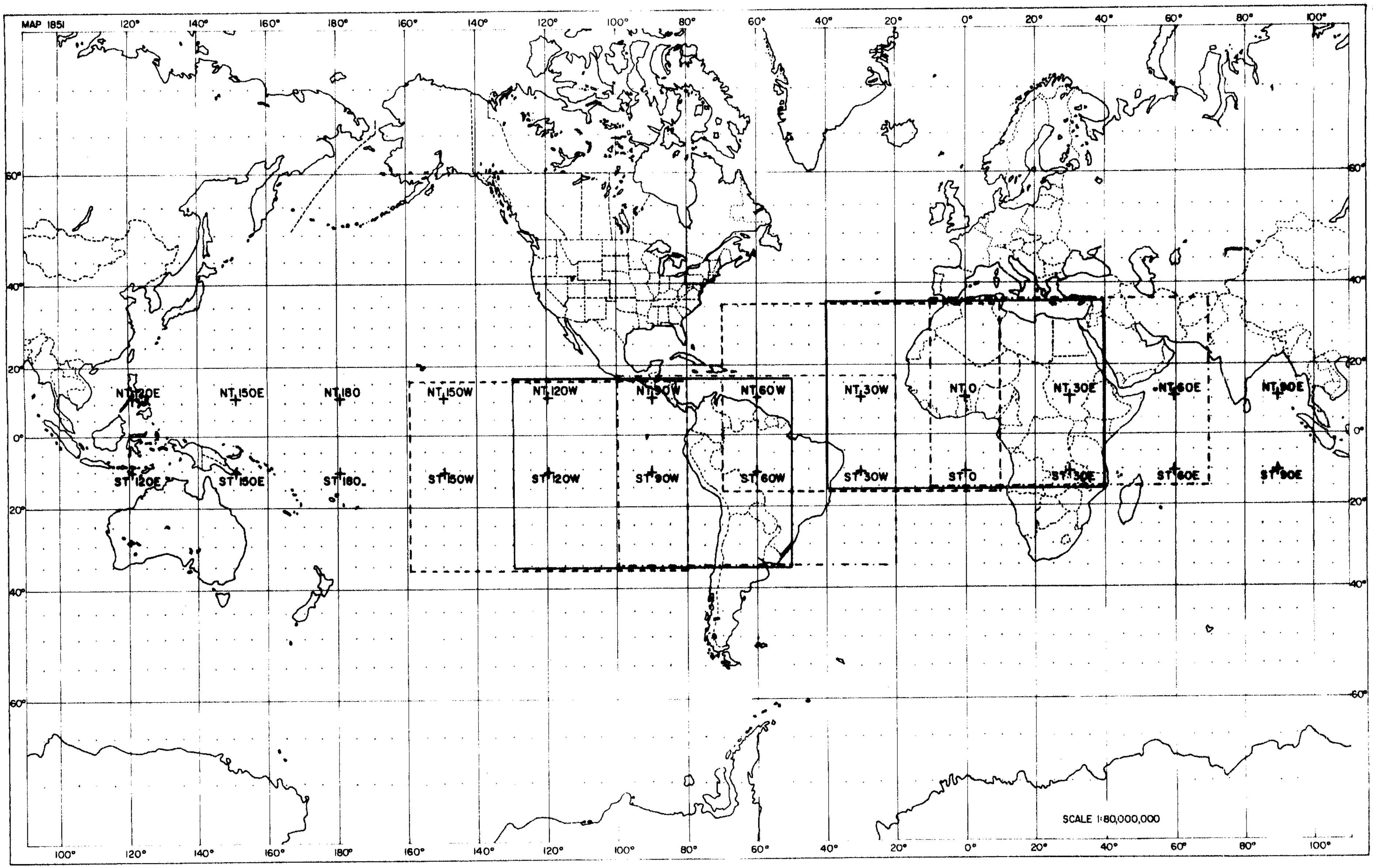

Figure 3-10 Northern Tropical (12) and Southern Tropical (12) WEFAX Charts for Sun-synchronous Transmission. Outlines indicate chart areas for 3 consecutive charts in each of the northern tropical and southern tropical areas. Center points of all charts are indicated, however.

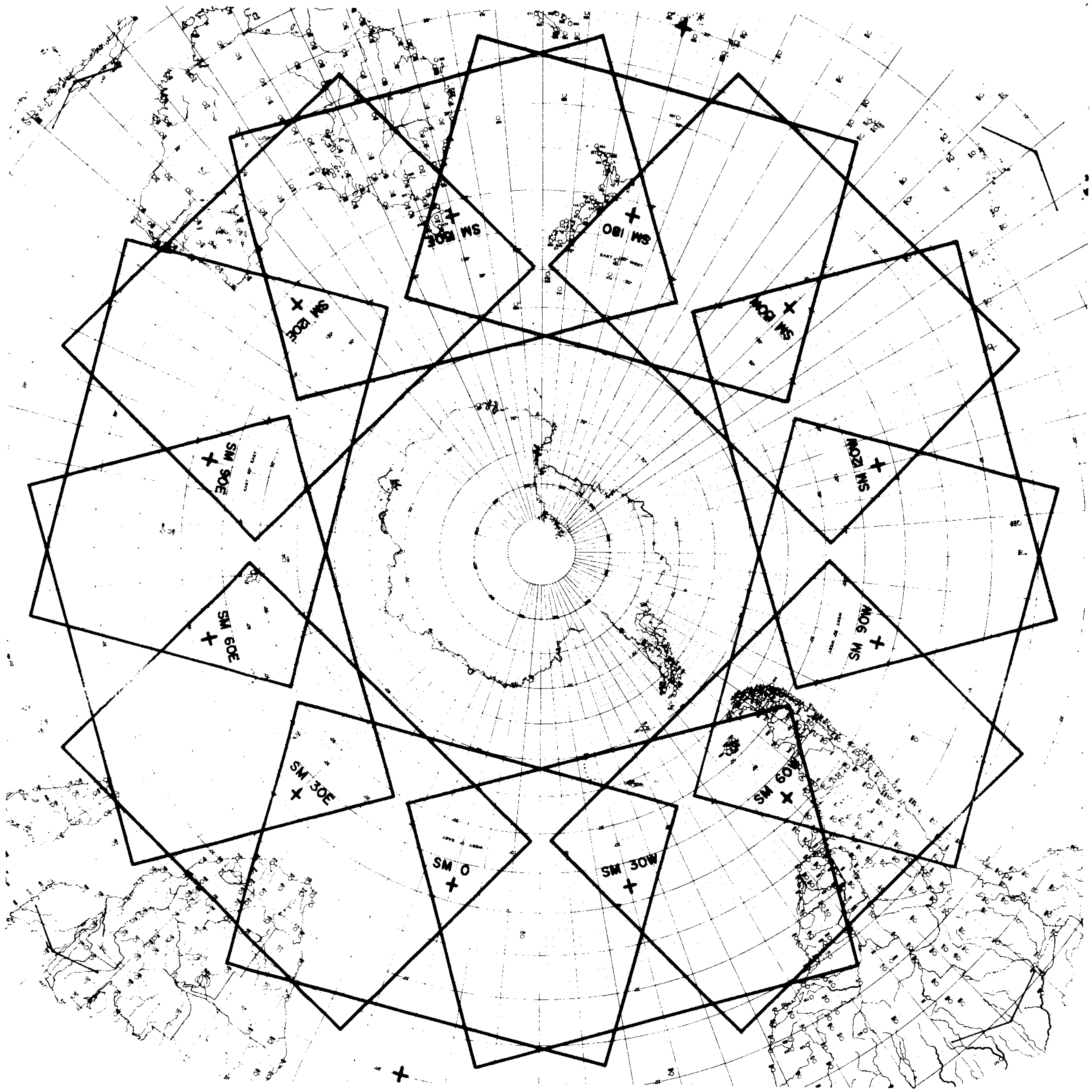

Figure 3-11 Southern Mid-Latitude WEFAX Charts (12) for Sun-synchronous Transmission

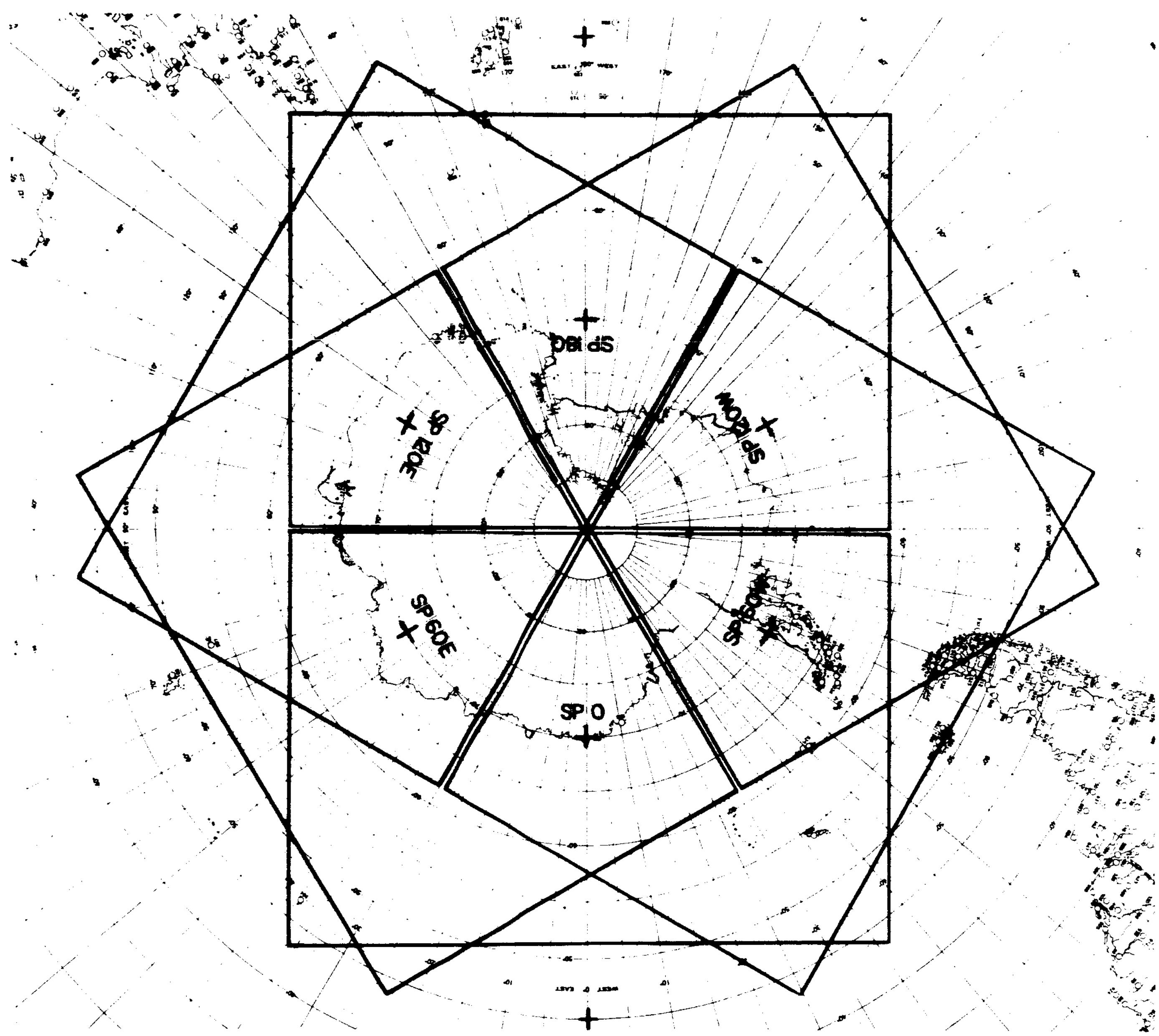

Figure 3-12 Southern Polar WEFAX Charts (6) For Sun-Synchronous Transmission.

3.4 Illustrations of Typical WEFAX Coverages

Figures 3-13 to 3-18 show the amounts of WEFAX coverage that could be received by typical stations at various latitudes. In developing these illustrations, it was again assumed that APT pictures were taken exactly at Ascending Node, and at 8.05 minute intervals, on the dayside of the orbit. The following satellite pass configurations are shown:

(1) an overhead pass, with immediately adjacent passes where applicable, and

(2) two side passes, such that the station is located midway between the two subsatellite tracks.

These two pass configurations illustrate the maximum and minimum WEFAX coverages provided to typical stations. Near the equator, the minimum coverage is given by an overhead pass, since no adjacent passes can be usefully acquired. In middle and polar latitudes, because of the convergence of the orbits, the overhead pass configuration will produce the maximum WEFAX coverage, since a station can also acquire side passes.

The full and dashed lines represent the lower and upper 5½", respectively, of the 8" x 11" area of a single WEFAX transmission. Each transmission begins with the southernmost portion of the chart in the lower half of the 8" x 11" area.

As the six examples show, for a 750 n. mi. altitude satellite and a 10% APT overlap, any station will be able to receive adequate WEFAX coverage. For example, the worst case (occurring at the equator with an overhead pass, Fig. 3-16) would still produce four, 8" x 5½" WEFAX charts, covering an area extending from 30° west to 50° east of the station and 36° both north and south of the station. It is obvious that the coverages illustrated in Figures 3-13 to 3-18 generally equal or exceed those specified as desirable in the beginning of Section 3.3.

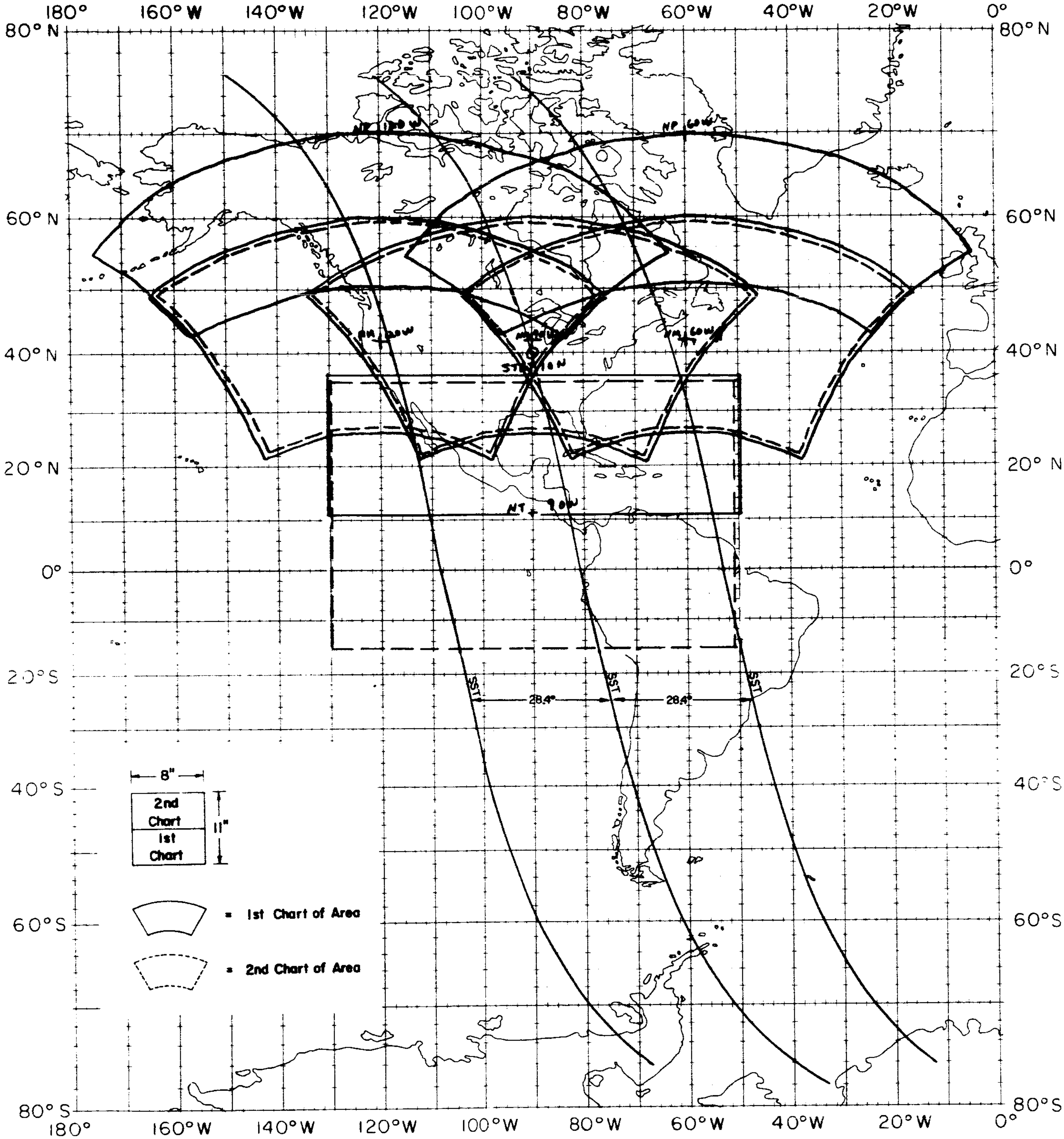

Figure 3-13 Maximum WEFAX coverage (an overhead pass) that would be acquired by a station at 40N from Sun-synchronous Transmission.

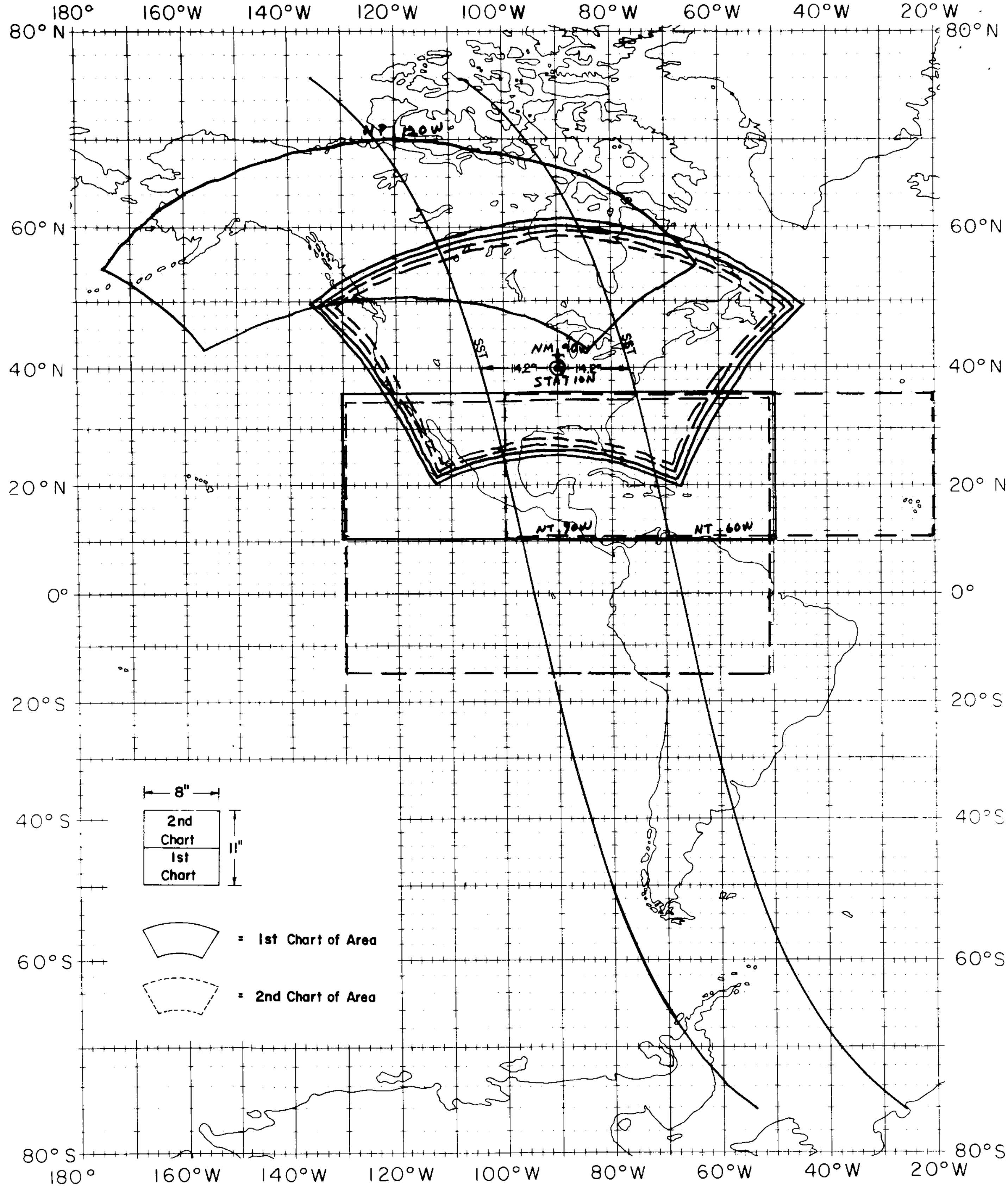

Figure 3-14 Minimum WEFAX coverage (two side passes) that would be acquired by a station at 40N from Sun-synchronous Transmission.

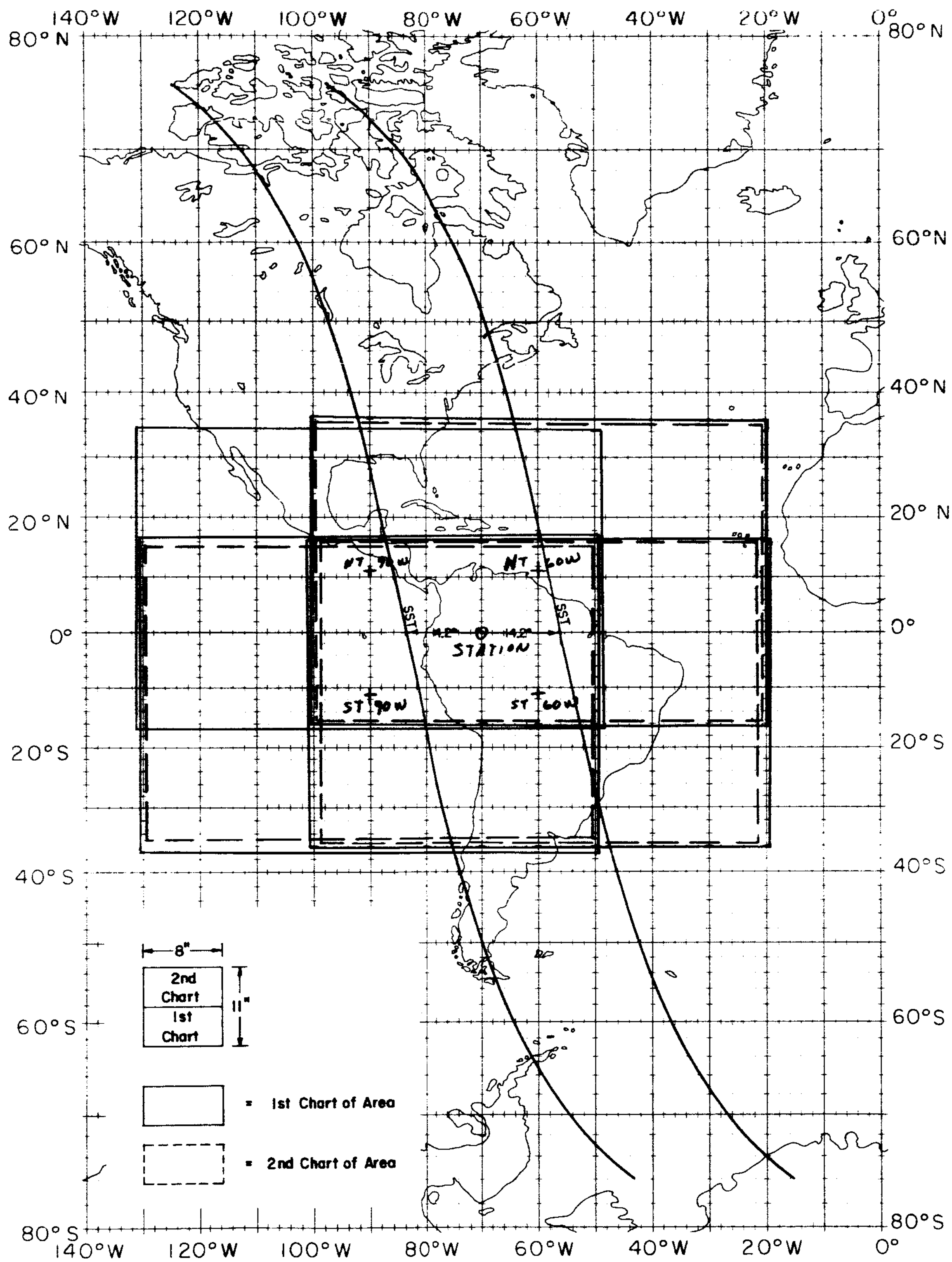

Figure 3-15 Maximum WEFAX coverage (two side passes) that would be acquired by a station at the Equator and 70W from Sun-synchronous Transmissions.

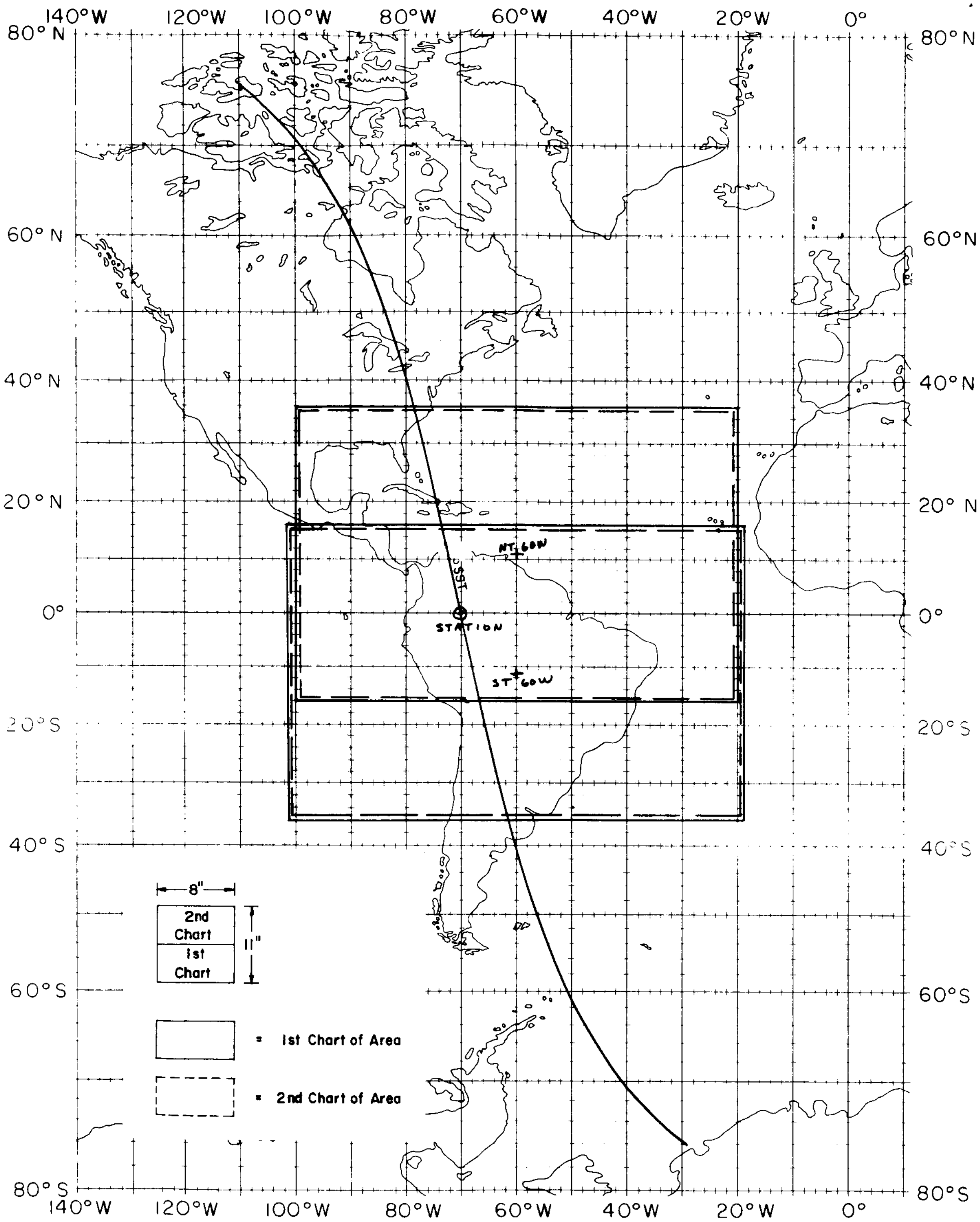

Figure 3-16 Minimum WEFAX coverage (an overhead pass) that would be acquired by a station at the Equator and 70W from Sun-synchronous Transmissions.

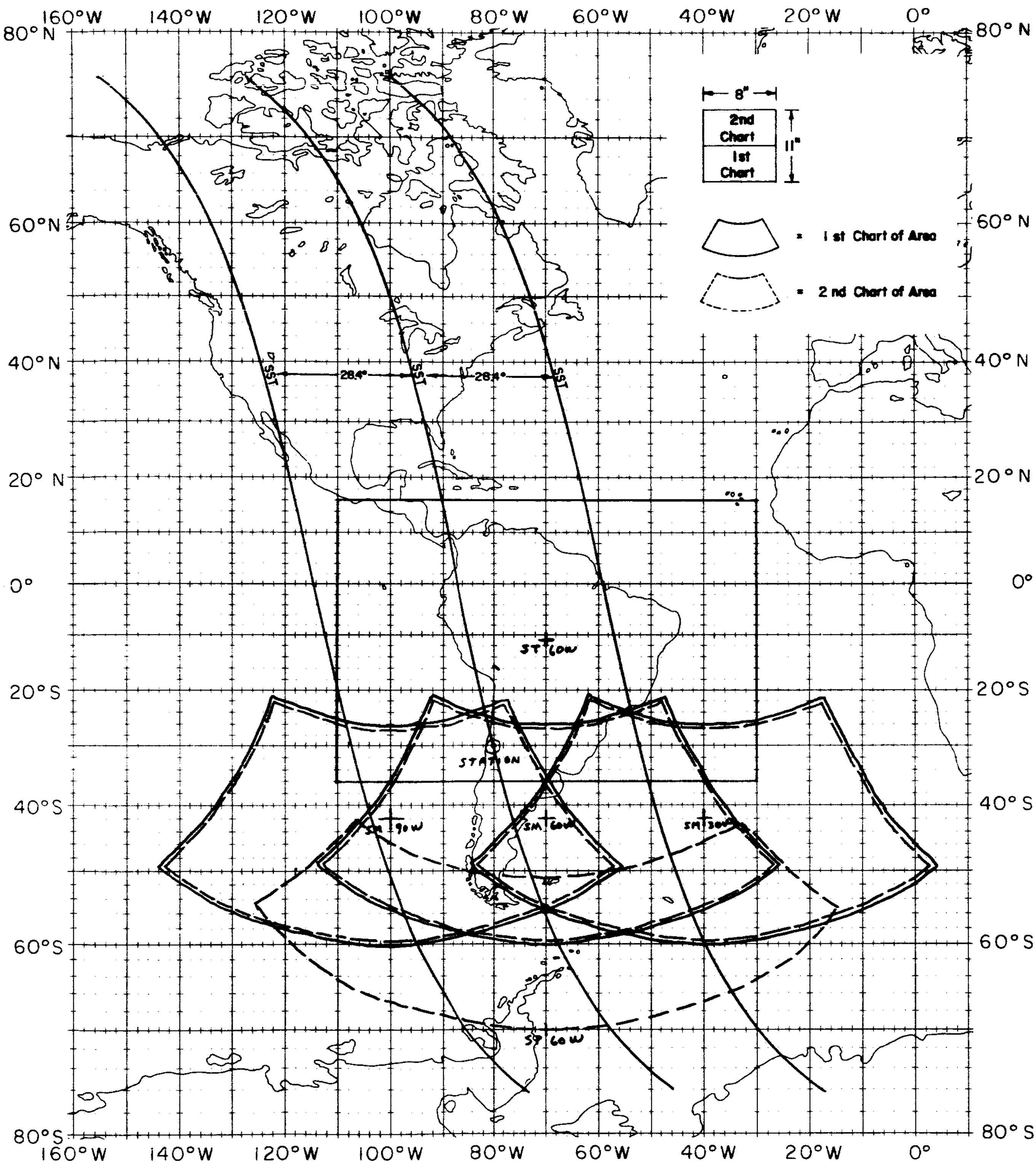

Figure 3-17 Maximum WEFAX coverage (an overhead pass) that would be acquired by a station at 30S, 70W from Sun-synchronous Transmission.

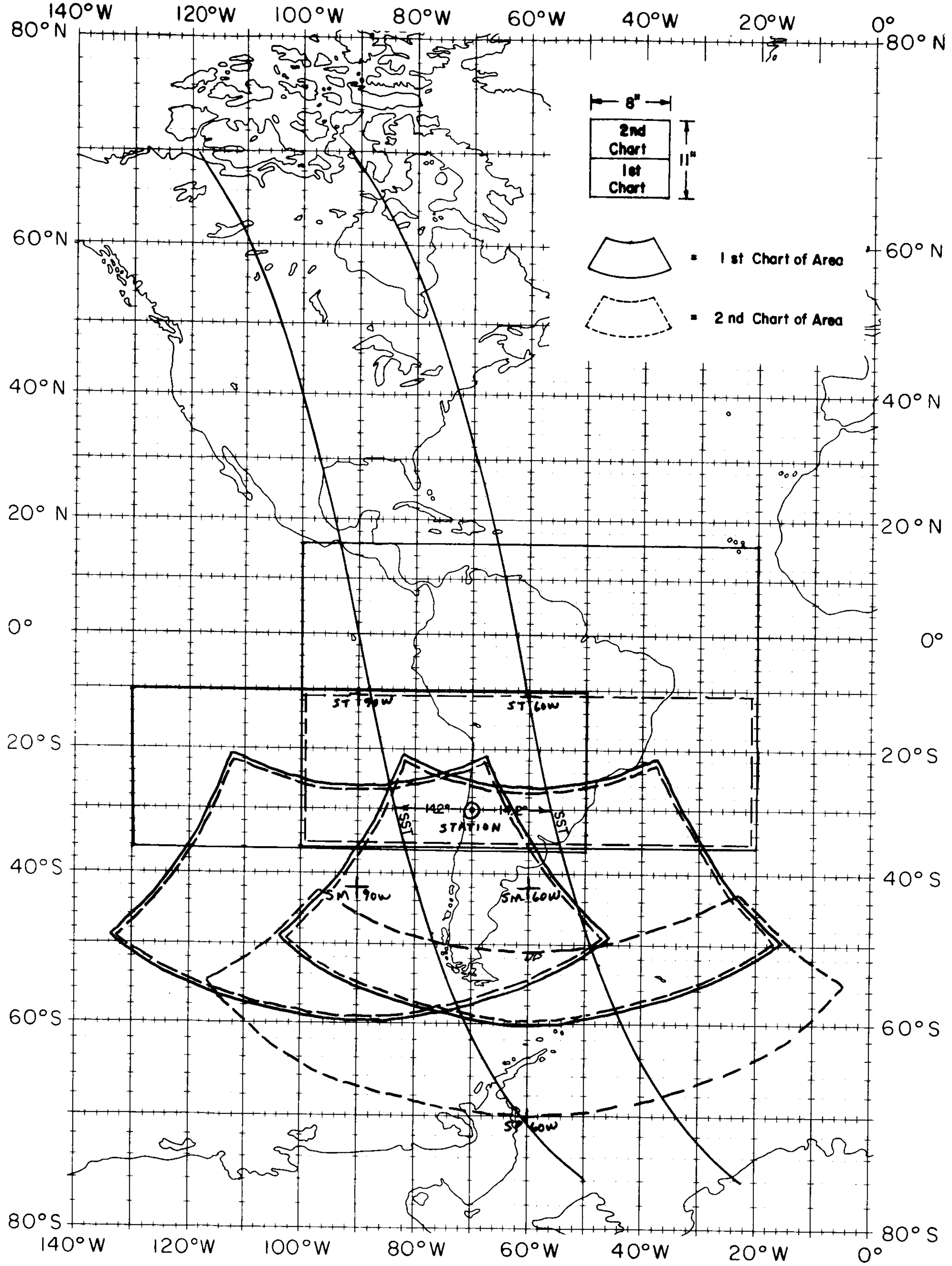

Figure 3-18 Minimum WEFAX coverage (two side passes) that would be acquired by a station at 30S, 70W from Sun-synchronous Transmission.

4. WEFAX TRANSMISSIONS FOR EARTH-SYNCHRONOUS SATELLITES

The high altitude of an earth-synchronous satellite (approximately 19250 n. mi. above the Equator) will permit stations from the edge of the Arctic to the edge of the Antarctic to receive its transmissions. An earth-synchronous satellite located over the Equator at 155 W would be able to transmit to at least the edges of all continents surrounding the Pacific Ocean. Figure 4-1 shows the acquisition areas, for zero and 10 degree minimum antenna elevation angles, for an earth-synchronous satellite located at 155 W.

The following discussions and illustrations have been prepared for the case of an earth-synchronous satellite located over 155 W, since this is the position presently planned for the first earth-synchronous satellite which is programmed to include a WEFAX capability (ATS-B). It is obvious, however, that the results presented can readily be generalized to the cases of other subpoint longitudes merely by shifting all points, lines, or areas, in longitude, by an amount equal to the longitude difference between the desired subpoint and 155 W.

It is also obvious that, for a system of three or four equally spaced earth-synchronous satellites, each satellite can, for most purposes, be treated as an independent system when considering WEFAX chart areas and programs. A possible exception might exist in the relatively small areas of longitudinal overlap but, even there, the simplicities that would result from essentially fixed antenna look angles may be sufficient to cause each receiving station to use, in most cases, only one of the two earth-synchronous satellites within its acquisition range. This would be particularly true if special earth-synchronous satellite WEFAX receivers, which would not require remotely controlled antennas, are developed. The problem of possible interference between transmissions from earth-synchronous and sun-synchronous satellites will be considered in Section 6.5.

At present, it is planned (by NASA) that there will be approximately 20 minutes available for WEFAX transmission every six hours. This corresponds to 8 x 48 inches of WEFAX record on the Fairchild facsimile recorder.

To best serve the interests of stations near the perimeter of the acquisition area, weather map coverages should extend beyond the acquisition perimeter. In middle latitudes, where weather systems generally travel from west to east, extensions 40 to 60 degrees west, and 20 to 30 degrees east, of the acquisition perimeter are considered adequate for covering areas of immediate meteorological interest to the fringe stations. In the tropical regions, where the weather generally comes from the east, extensions 30 to 40 degrees east, and 20 to 30 degrees west, should be sufficient.

Again following the general present practice in operational meteorology, the weather charts should be Polar Stereographic projections at middle and high latitudes, and Mercator Projections in the tropics. It seems preferable, for consistency, to use the same scale maps for both the earth-synchronous and the sun-synchronous satellite transmissions. The scales adopted for the sun-synchronous case are 1:30 million for the polar stereographic projection, and 1:40 million for the Mercator projection (see Section 3. 3).

Analyses have shown that, if these map scales are used for the earth-synchronous case, an 8 x 48 inch WEFAX area will not be sufficient to adequately cover the entire acquisition area and the extension thereof discussed above. We are, therefore, faced with the following alternatives:

(1) sacrifice full coverage
(2) alternate the areas covered from one transmission to another
(3) use a smaller scale map
(4) lengthen the WEFAX transmission time

Of these four alternatives, the first two are especially undesirable since they would limit either the coverage or the amount of data transmitted. The most desirable alternative appears to be a slight lengthening of the WEFAX transmission time, which permits both full coverage and the use of the same map scales employed for the sun-synchronous satellite. It appears that 8 x 60 inches of WEFAX, or 25 minutes of transmission time, would be adequate. This would permit four 8 x 10 inch charts on the 1:30 million polar stereographic projection (to cover the middle and high latitude regions in both hemispheres), and one 8 x 20 inch chart, on the 1:40 million Mercator projection, to cover the tropics. Figures 4-2, 4-3, and 4-4, and Table 4-1, illustrate the proposed map coverage.

If the transmission times must be restricted to 20 minute periods, the best procedure would seem to be the use of a smaller scale for the south polar area, where a present paucity of meteorological data permits (and often requires) less detailed analyses. An 8 x 8 inch southern hemisphere chart on a 1:60 million polar stereographic projection would provide adequate coverage at the cost of a lesser and non-uniform scale. In fact, it would cover more area than the two 8 x 10 inch charts at at 1:30 million scale. In this way, the total WEFAX area could be restricted to 8 x 48 inches, or a 20 minute transmission period. The coverage of this alternatively proposed 8 x 8 inch chart is illustrated by the dashed area in Figure 4-4.

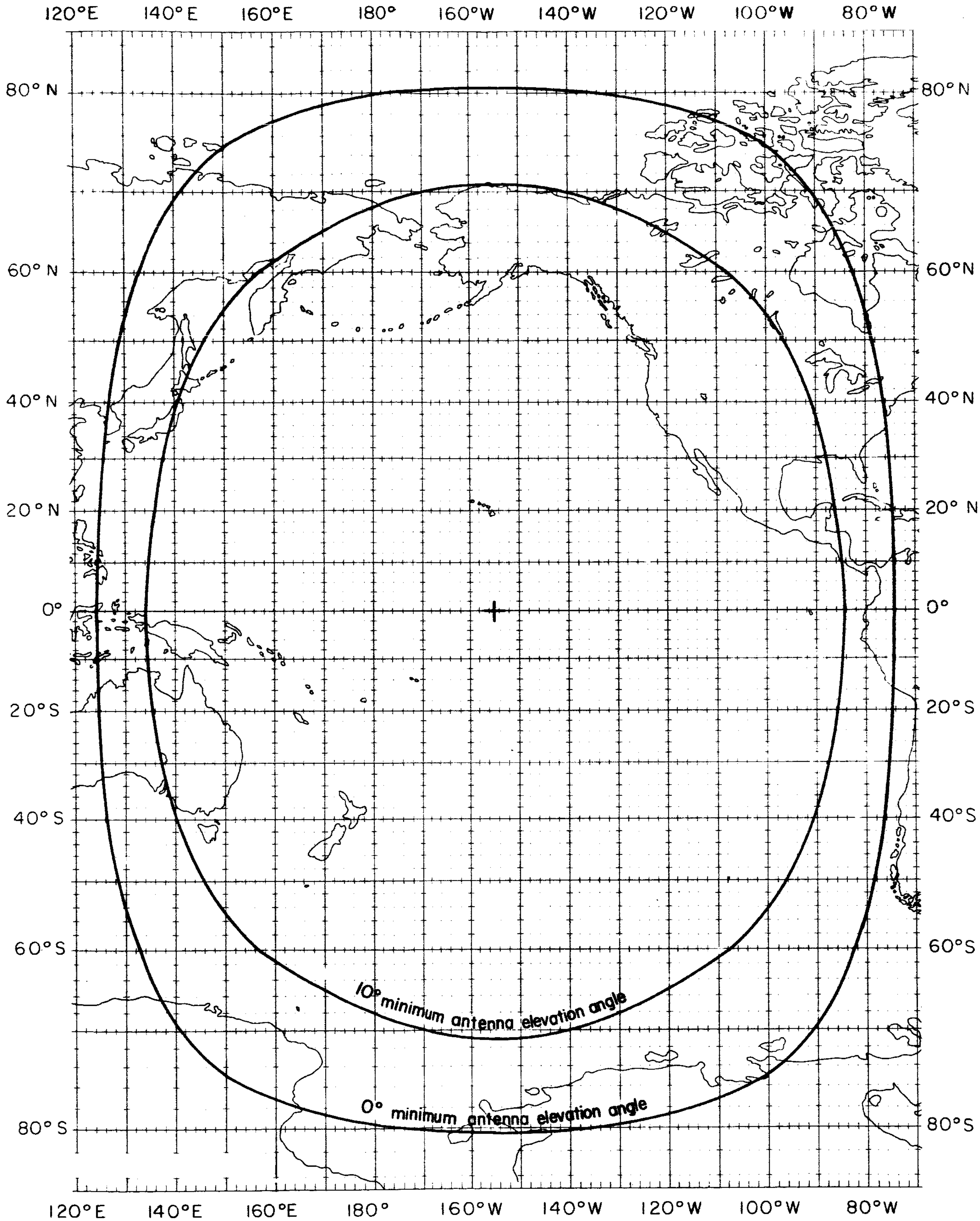

Figure 4-1 Acquisition Areas for an Earth-Synchronous Satellite located over the Equator and 155° W Longitude for zero and ten degree minimum antenna elevation angles.

As a less desirable alternative, we might sacrifice coverage in the Southern Hemisphere by using an 8 x 8 inch chart with a 1:30 million scale.

TABLE 4-1

Earth-Synchronous Satellite WEFAX Chart Designators

CODE	DESCRIPTION
NPMW	Northern Polar and Mid-Latitude Chart-Western Section 1 : 30,000,000 Polar Stereographic
NPME	Northern Polar and Mid-Latitude Chart-Eastern Section 1 : 30,000,000 Polar Stereographic
TROP	Tropical Chart; 1 : 40,000,000 Mercator
SPMW	Southern Polar and Mid-Latitude Chart-Western Section 1 : 30,000,000 Polar Stereographic
SPME	Southern Polar and Mid-Latitude Chart-Eastern Section 1 : 30,000,000 Polar Stereographic
SPM	Alternative Southern Polar and Mid-Latitude Chart; 1 : 60,000,000 Polar Stereographic

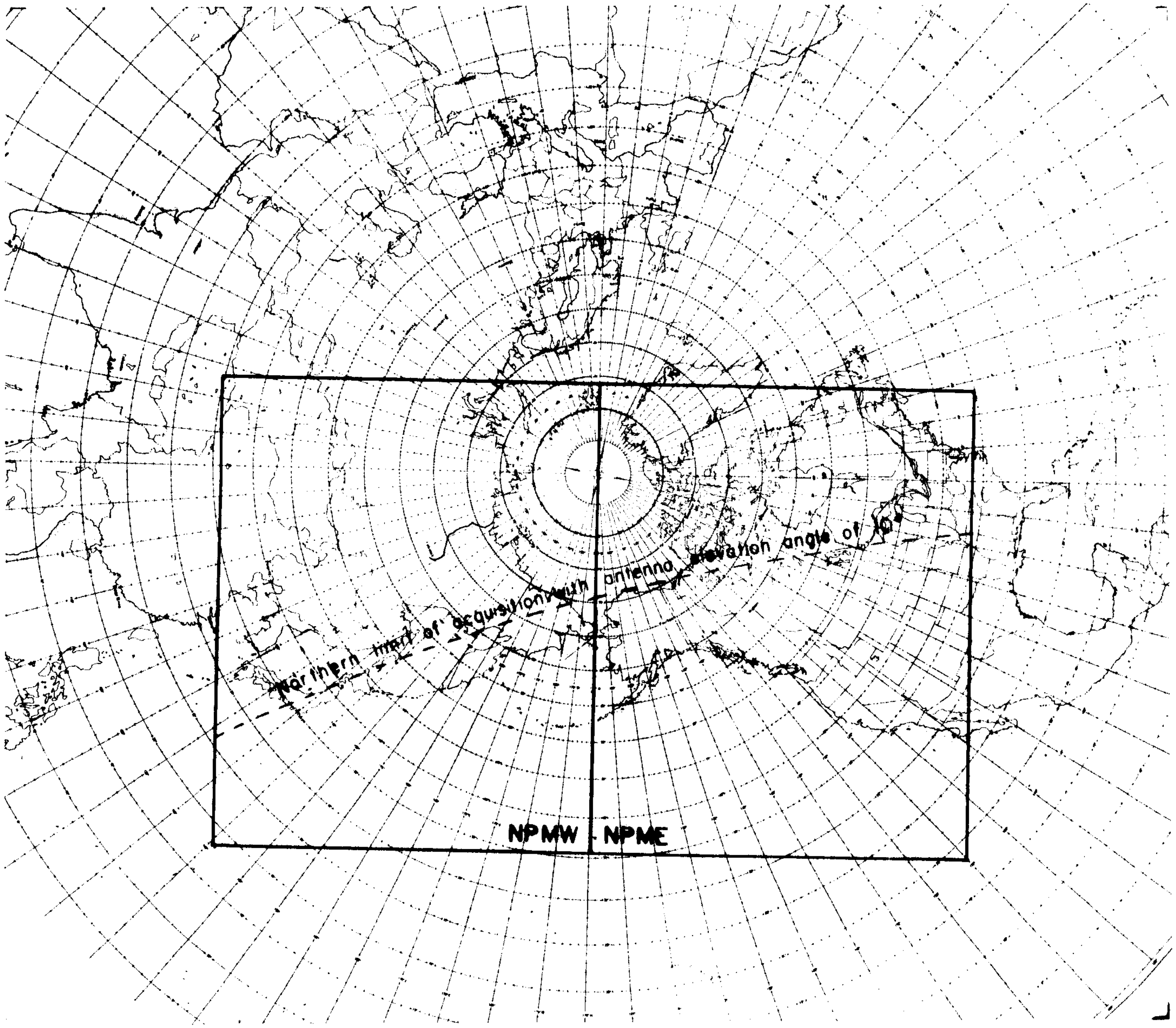

Figure 4-2 Northern Polar and Mid-Latitude WEFAX Charts For An Earth-Synchronous Satellite Located Over 155° W Longitude.

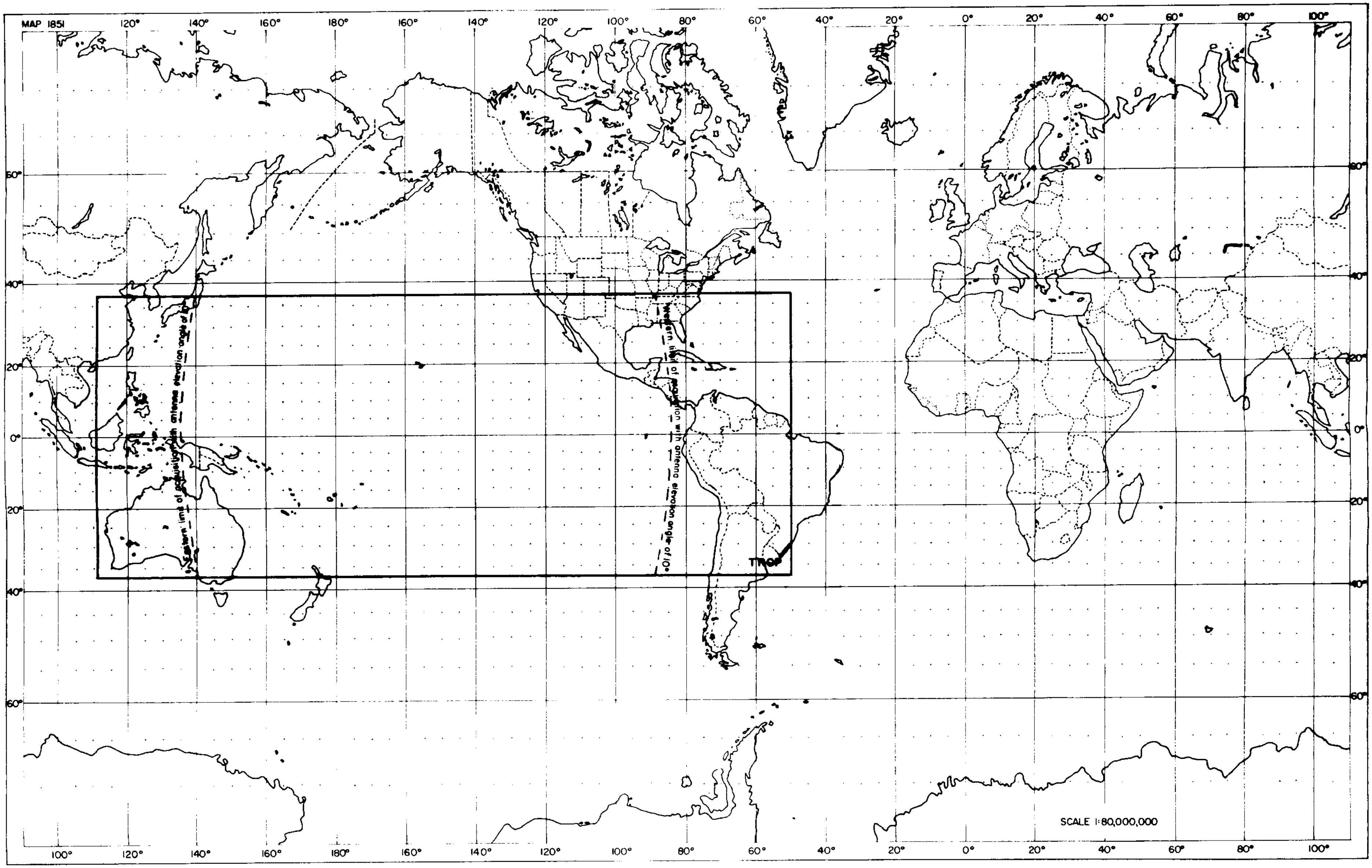

Figure 4-3 Tropical WEFAX Chart for an Earth-Synchronous Satellite located over 155°W Longitude.

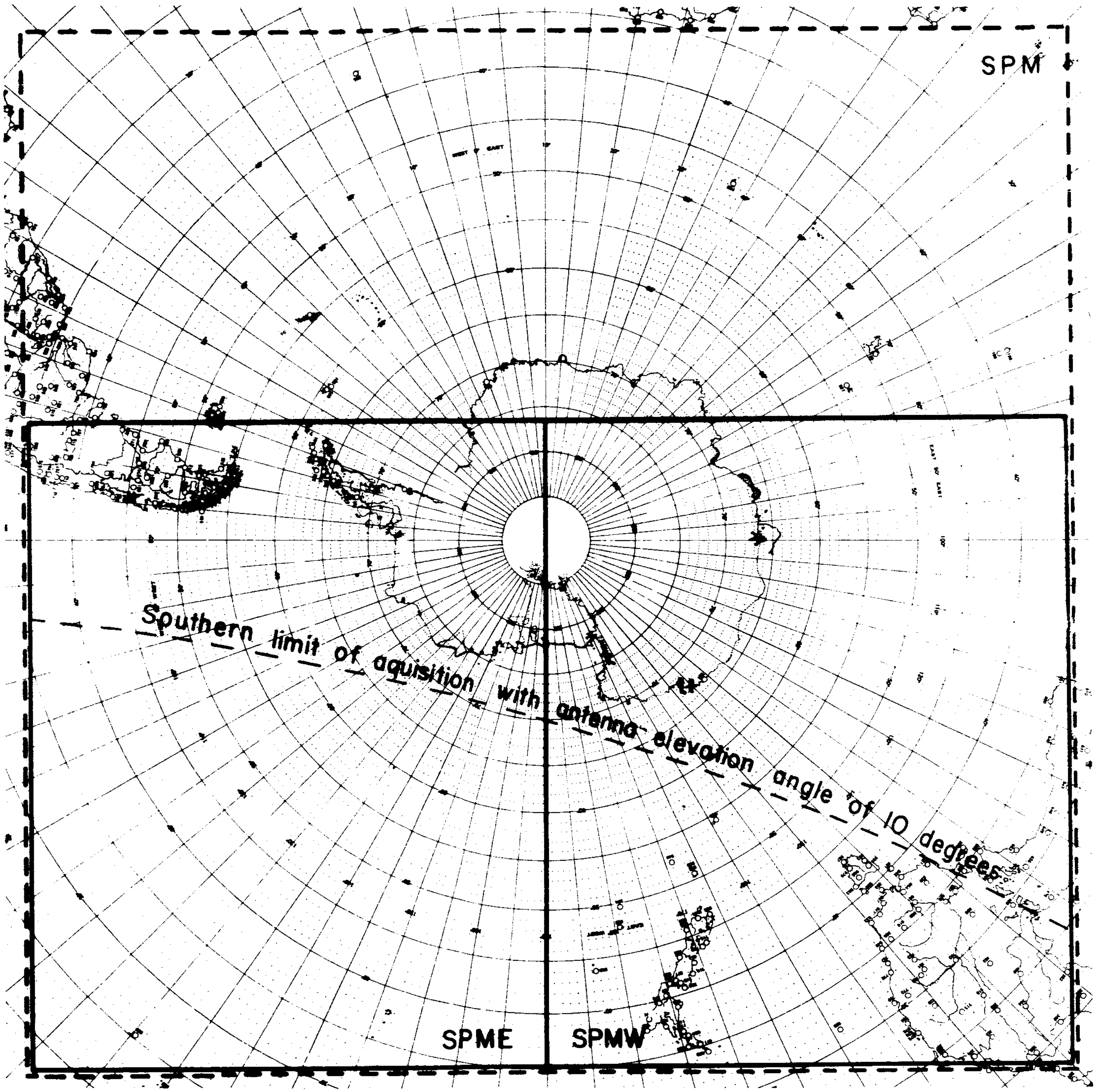

Figure 4-4 Southern Polar and Mid-Latitude WEFAX Charts for an Earth-Synchronous Satellite located over 155° W Longitude. The solid lines depict the two areas for a map scale of 1:30 million, and the dashed lines the alternative single map at a scale of 1:60 million (see text).

5. TYPES AND CONTENTS OF WEFAX CHARTS

5.1 General Considerations

A sampling of the opinions of a number of experienced forecasters was made to determine the types of weather maps that would be most useful in particular areas, and the priorities that should be assigned if it was not possible to transmit all the charts that might be desired. The results of this sampling are presented and illustrated in Section 5.3.

After this sampling and its analysis had been completed, we were gratified to note that the results obtained were entirely consistent with the independent viewpoints of the USWB's National Meteorological Center, as judged from the charts listed as "First Increment WMC Products" in Table 3, page 7, Appendix A ("World Weather Watch First Stream Improvement Plan, Phase I") of Reference 5.

Ideally, each chart for each area should be updated at least every twelve hours (possibly every six hours for surface charts where the frequency of available observations permit), but this will not be possible with only one sun-synchronous satellite in operation, unless nighttime transmissions are made in the absence of DRIR. With one or more earth-synchronous satellites, or two concurrent sun-synchronous satellites spaced approximately six - eight hours apart (e.g., 0900 and 1500, or 0800 and 1600, local time), it would be possible to provide two of the more significant types of weather charts for each area each day.* The observation time, or valid prognostic time, of each chart of the same type and area would be twelve hours later than that of the immediately previous one, although the transmission intervals may not be uniform in the sun-synchronous case (e.g., 6 or 8 versus 18 or 16 hours).

5.2 Chart Content

Since the principal users of WEFAX charts will be in remote areas of fairly sparse data, the detailed weather charts available for the continental United States and Europe are neither possible nor required. The charts need not, and in general should not, include plotted weather data. They should, however, include the various types of isolines, pressure centers, and/or fronts, and in some cases weather depiction. In tropical regions, streamlines and isotachs should be used, if possible, rather than isobars or contours. By omitting the plotted weather data, and by restricting the number or types of isolines, the charts can be fully legible even at the somewhat reduced scales required, and will provide the forecaster with the

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* See, however, Section 6.4.

broad-scale weather features for a comparatively large area to supplement his (possibly somewhat more detailed) local area information. Standard analysis conventions, notations, and symbols should be used on all charts. A single line legend should unambiguously identify the type of chart and the valid (observation or prognostic) time; e.g., 500MB ANAL 1200Z 16NOV65. This legend should be placed at both the top and bottom of the chart, so that any partial chart received can be identified. All alphanumeric notations must be in large enough figures to be clearly readable after undergoing the necessary scanning, transmission, and recording processes.[6]

5.2.1 Composite Charts

When the chart contents are simplified, it becomes possible to use composite charts by superimposing two types of charts and making them a single transmission. For example, a simplified surface analysis or prognosis (with fronts, pressure centers, and significant weather) can readily be combined with a 500 millibar analysis or prognosis (contours and isotherms) as illustrated in Figure 5-1. An analysis and prognosis for the same level might also be combined and depicted on a single chart. Our analyses have determined that, in order to provide a sufficient variety of data to all stations, it will be necessary in some areas to use such composite charts when only one sun-synchronous satellite is in operation.

5.3 Types of Charts

The chart requirements of stations located at different latitudes can be divided into two categories. One category is that for temperate and polar regions, and the other is that for the tropical regions. The different requirements of the two types of areas are derived mainly from differences in atmospheric processes, relationships, and structure, and the problems they present as regards weather analysis and forecasting. For example, the geostrophic wind relationship, a basic and highly applicable principle in higher latitudes, is of little use in low latitudes.

5.3.1 Temperate and Polar Regions

In temperate and polar regions, the charts to be transmitted should, in so far as possible, provide both analyses and prognoses. The two most basic charts for these regions are those for the surface and the 500 millibar levels. The WEFAX

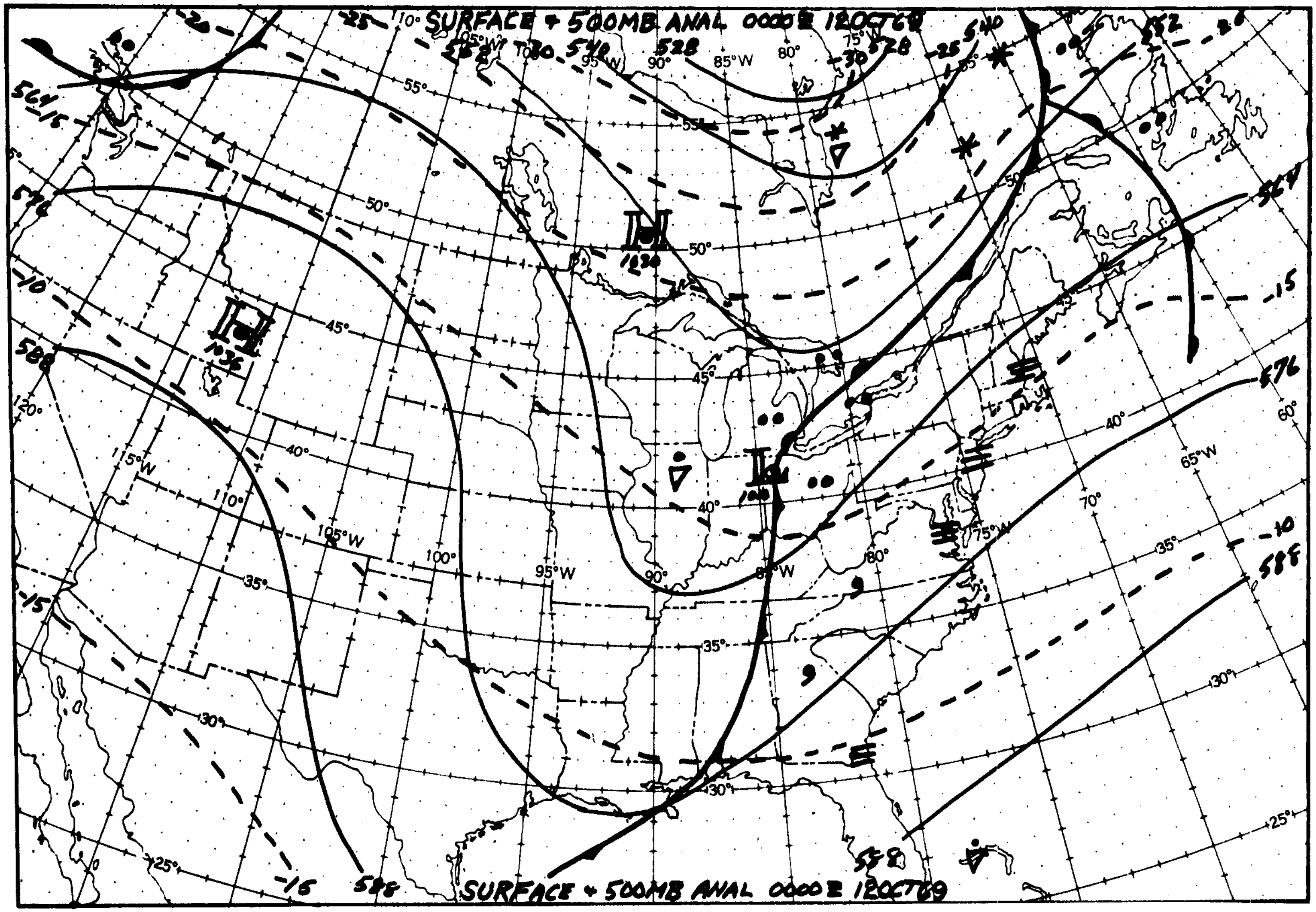

Figure 5-1 Simplified Surface Analysis, with 500 mb analysis superimposed.

charts recommended are listed below as a function of the total number of charts that can be transmitted to a given area on one or more adjacent passes or acquisitions:

1. Only one chart possible
   a. Simplified surface analysis, with 500 millibar contours and isotherms superimposed (see Figure 5-1).*
2. Two charts
   a. Simplified surface analysis, with 500 millibar analysis superimposed (see Figure 5-1).
   b. Simplified 36 hour surface prognosis (including simplified Weather Depiction) with 36 hour 500 millibar prognosis superimposed (see Figure 5-2).
3. Three charts
   a. Standard surface analysis (see Figure 5-3).
   b. Standard 500 millibar analysis (see Figure 5-4).
   c. Simplified 36 hour surface prognosis, with 36 hour 500 millibar prognosis superimposed (see Figure 5-2).
4. Four charts
   a. Standard surface analysis (see Figure 5-3).
   b. Standard 500 millibar analysis (see Figure 5-4).
   c. 36 hour surface and weather depiction prognosis (see Figure 5-5).
   d. 36 hour 500 millibar prognosis (see Figure 5-6).

If more than four charts of an area can be transmitted within a relatively short period of time, as in some multiple satellite cases, the 200 and 300 millibar analyses, and the 72 hour or 5 day prognoses, seem the most suitable. Since the 200 and 300 millibar analyses would be completely analogous to the 500 millibar analysis (Figure 5-4), and the longer period prognoses to the 36 hour prognoses (Figures 5-2, 5-5, and 5-6), they need not be specifically illustrated here.

5.3.2 Tropical Regions

For the tropical regions, it would also be desirable to provide both analyses and prognoses, although the demand for prognoses may be somewhat more debatable

*In Figures 5-1 through 5-9, the charts are reproduced in this report in exactly the sizes, scales, and degrees of detail proposed for WEFAX transmission, assuming reproduction by a Fairchild facsimile recorder and the adoption of the formats recommended in previous sections of this report.

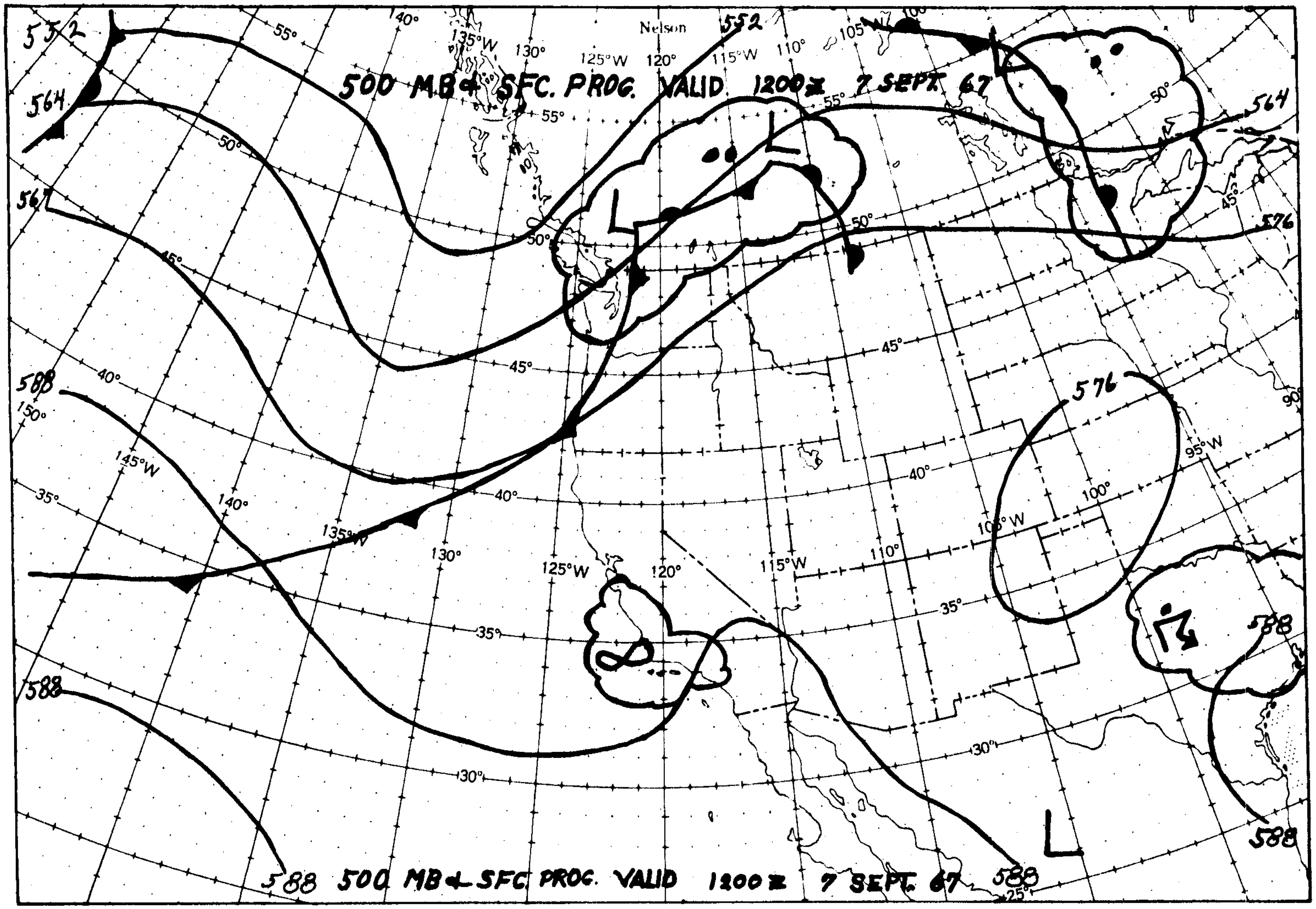

Figure 5-2 36 hour Surface and 500 mb Prognosis.

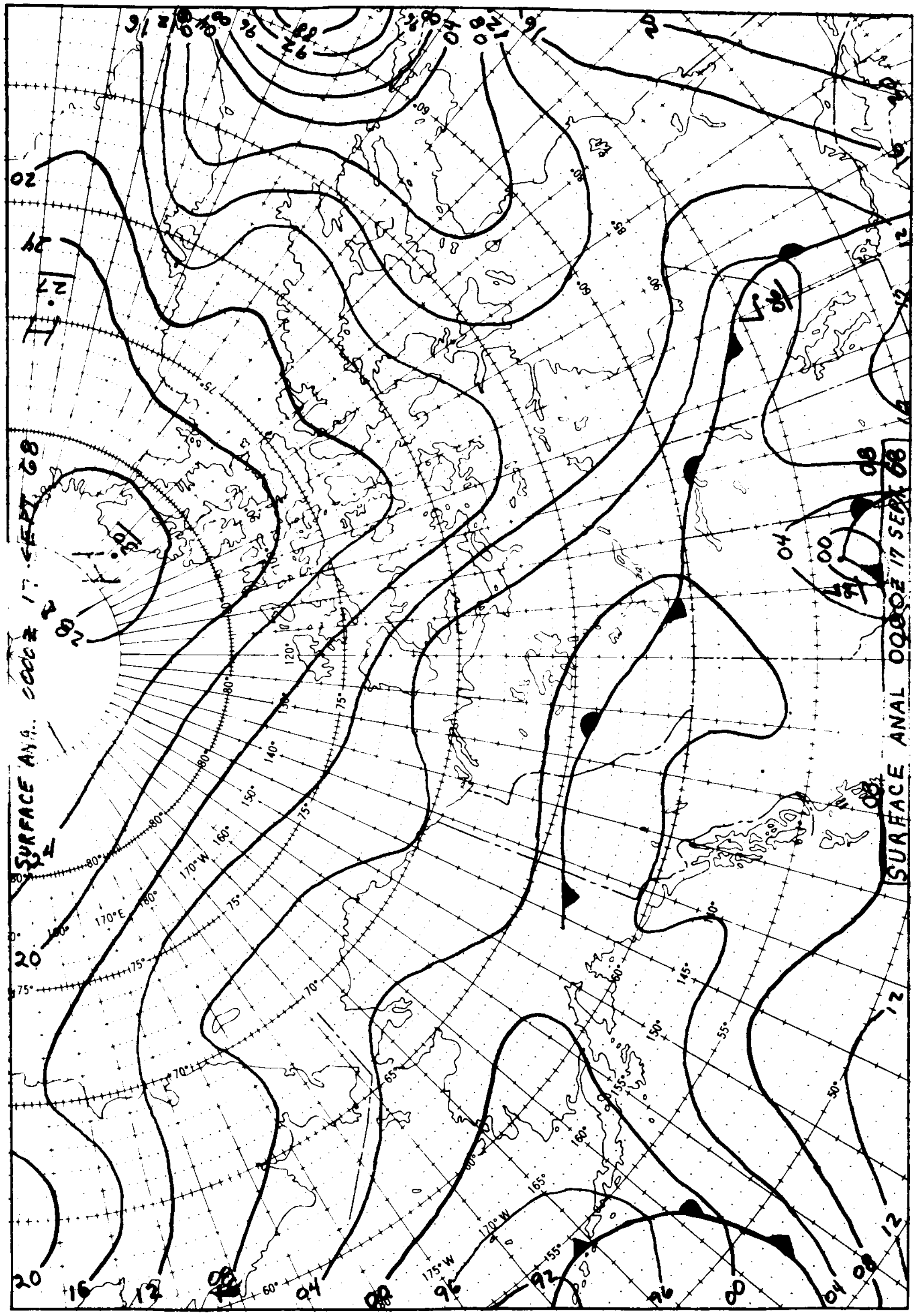

Figure 5-3 Surface Analysis

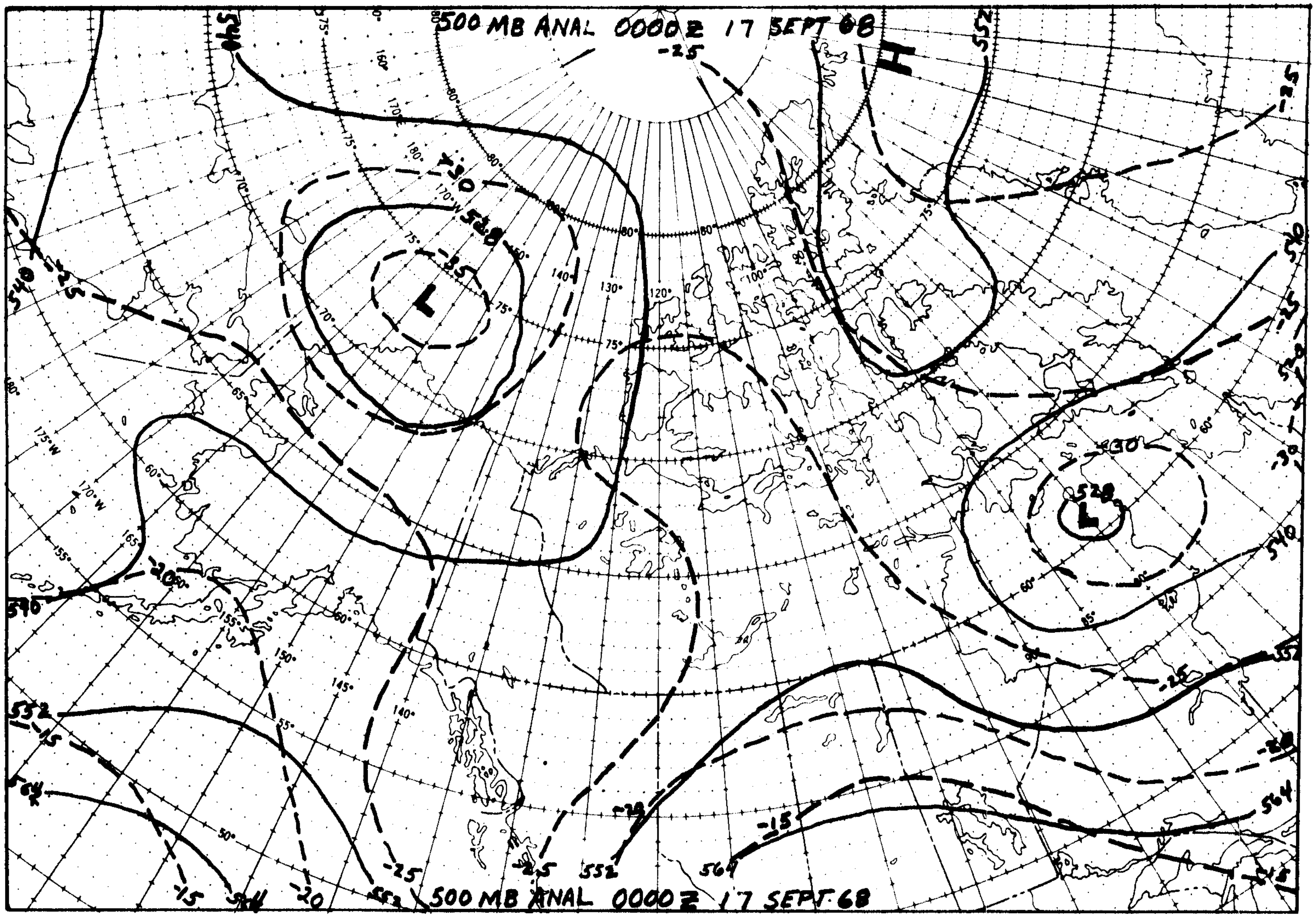

Figure 5-4 500 mb Analysis.

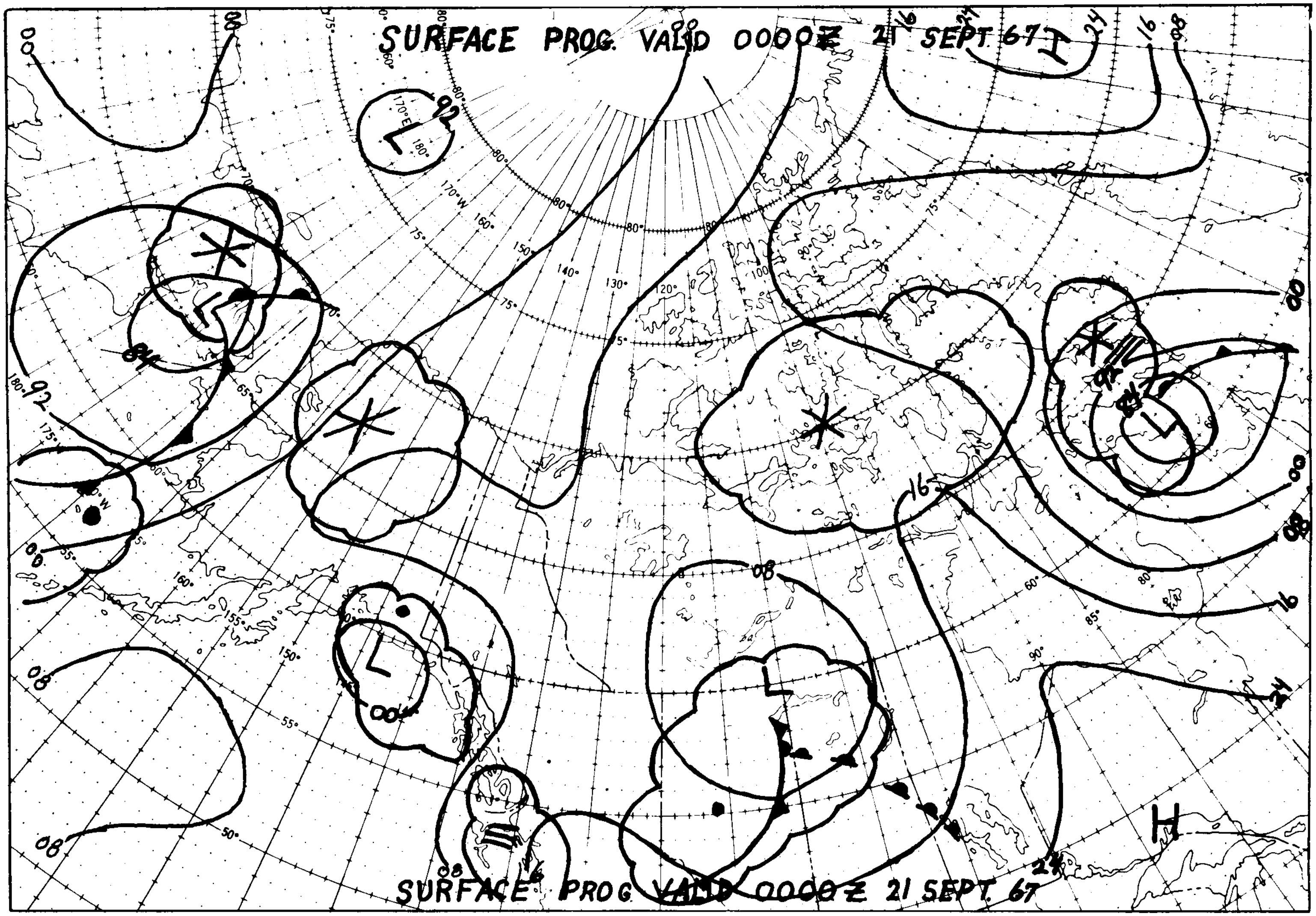

Figure 5-5 36 hour Surface Prognosis, with weather depiction.

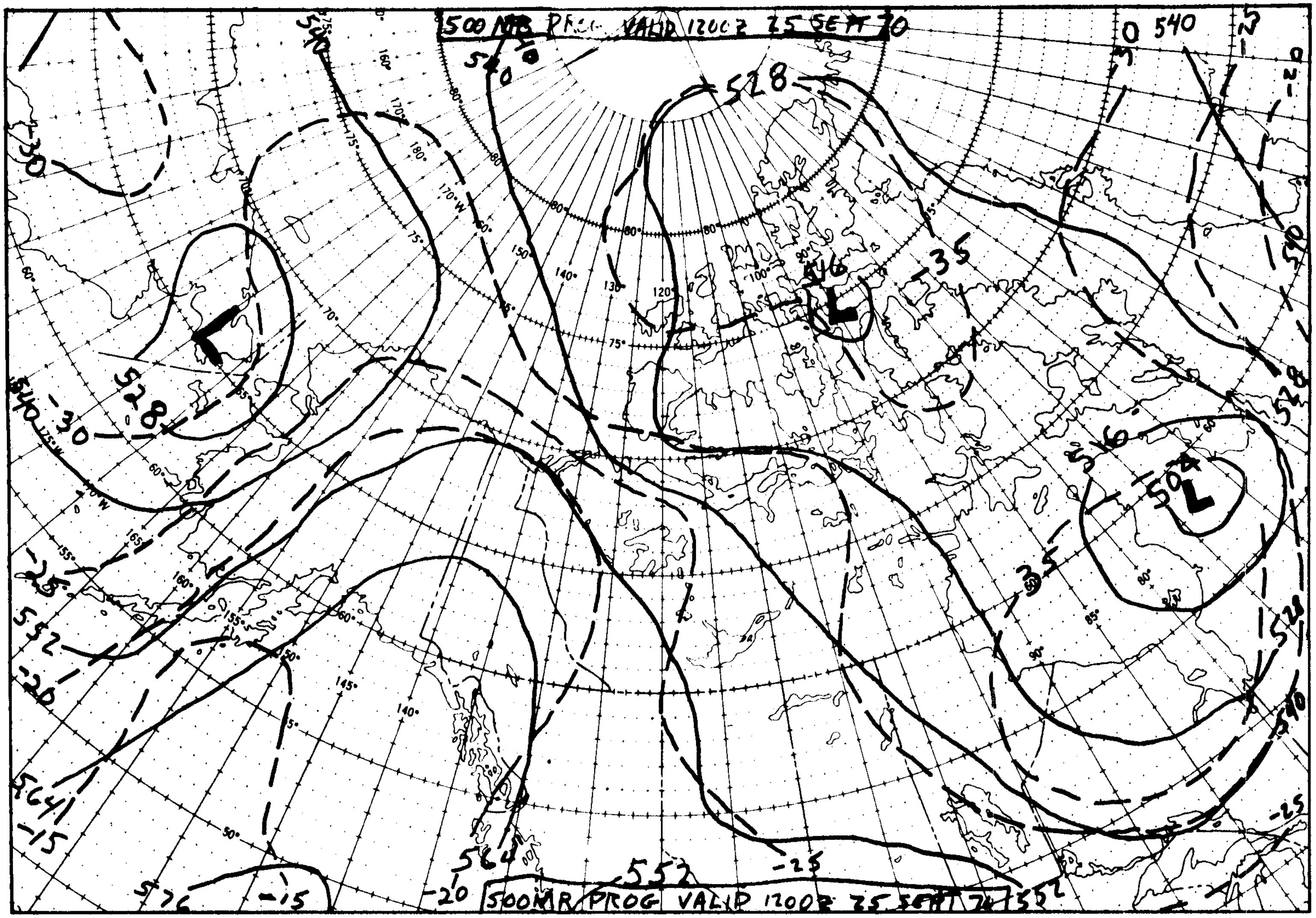

Figure 5-6 36 hour 500 mb Prognosis.

than for the polar and temperate regions. The differences in the degree of demand for prognoses between the tropics and higher latitudes derive from two considerations:

1. Except during the final transformation of lesser tropical cyclones to hurricanes or typhoons, system developments and movements in the tropics are normally far less rapid than in higher latitudes.

2. Until reliable,objective (i. e., numerical weather prediction type) prognostic techniques applicable to the tropics are developed, many local forecasters will hesitate to rely on subjective prognoses prepared by others, even if these prognoses are prepared at fully and expertly staffed weather centers.

The principal tropical weather chart is that for the surface (or for the 1000 millibar level, or for a layer extending from the surface to a level of some 6000-8000 feet). The next most significant chart which is generally prepared is probably that for a near-tropopause level or layer (i. e., 200 millibar). Third in rank is a chart for the 500 or 600 millibar level. (Although the present standard tropical level in the mid-troposphere is the 500 millibar level, it appears this level has been adopted more as an extension of its use in higher latitudes, or because of the most general use of this level by modern propeller aircraft, than from any real consideration of tropical weather processes. Recent investigations[8, 9] suggest that the use of the 600 millibar level would have much to recommend it, especially as regards the formative and developmental stages of tropical disturbances and cyclones.)

While ideally the tropical analyses (and any prognoses) at all levels should be presented in the format of streamlines and isotachs, in some areas and for some weather services the isobaric format is still used for tropical surface analyses and these practices must be considered in the final WEFAX program formulations.

The following tabulation presents the recommended tropical WEFAX charts as a function of the total number of charts that can be transmitted to a given area on one or more adjacent passes or acquisitions:

1. Only one chart possible
    a. Surface analysis, possibly as isobars or fronts (see Figure 5-7), but preferably as streamlines and isotachs. (The streamline-isotach format would resemble that of the 200 millibar tropical analysis in Figure 5-8.)

2. Two charts
    a. Surface analysis (see Figure 5-7).
    b. 200 millibar analysis (see Figure 5-8).

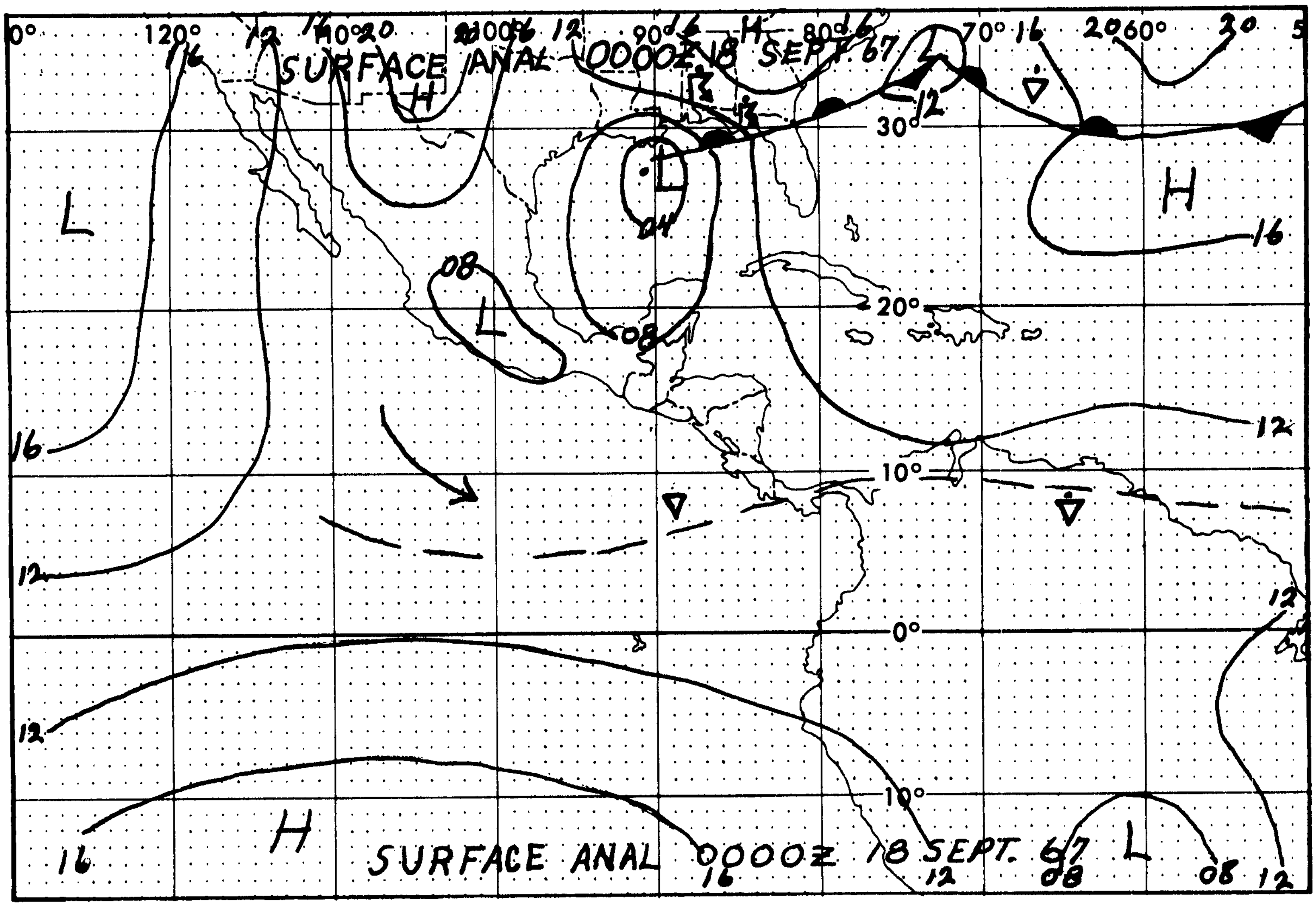

Figure 5-7 Tropical Surface Analysis (Isobar Format)

3. Three charts

   a. Surface analysis (see Figure 5-7).

   b. 200 millibar analysis (see Figure 5-8).

   c. 500 millibar analysis (see Figure 5-9), or 600 millibar analysis.

4. Four charts

   a. Surface analysis (see Figure 5-7).

   b. 200 millibar analysis (see Figure 5-8) .

   c. 500 millibar analysis (see Figure 5-9), or 600 millibar analysis.

   d. 36 hour surface prognosis, with weather depiction (resembling Figure 5-7 or 5-8).

If more than four charts of an areas can be transmitted, as in some multiple satellite cases, the 700 and 850 millibar analyses, and the 72 hour prognoses, seem the most suitable. Again, these are not specifically illustrated since they would be completely analogous to the charts in Figures 5-7, 5-8, and/or 5-9.

5.4 Availability of Analyses

The types of charts that can be transmitted for various areas will, or course, depend upon what is or can be made available at the entry point of the WEFAX system. The National Meteorological Center (Washington World Center) already routinely prepares all the proposed extratropical northern hemisphere WEFAX analyses or prognoses, although some readily made scale adjustments, simplifications by omission, or combinations may be required to fit the specifically proposed WEFAX formats. It is understood that the Washington World Center will extend the area of coverage of its analyses and prognoses throughout the tropics and the Southern Hemisphere on a once per day basis in FY 1967, and on a twice per day basis in FY 1969. The Washington Center would then be able to provide all the analyses or prognoses basic to the weather charts proposed for WEFAX transmissions.

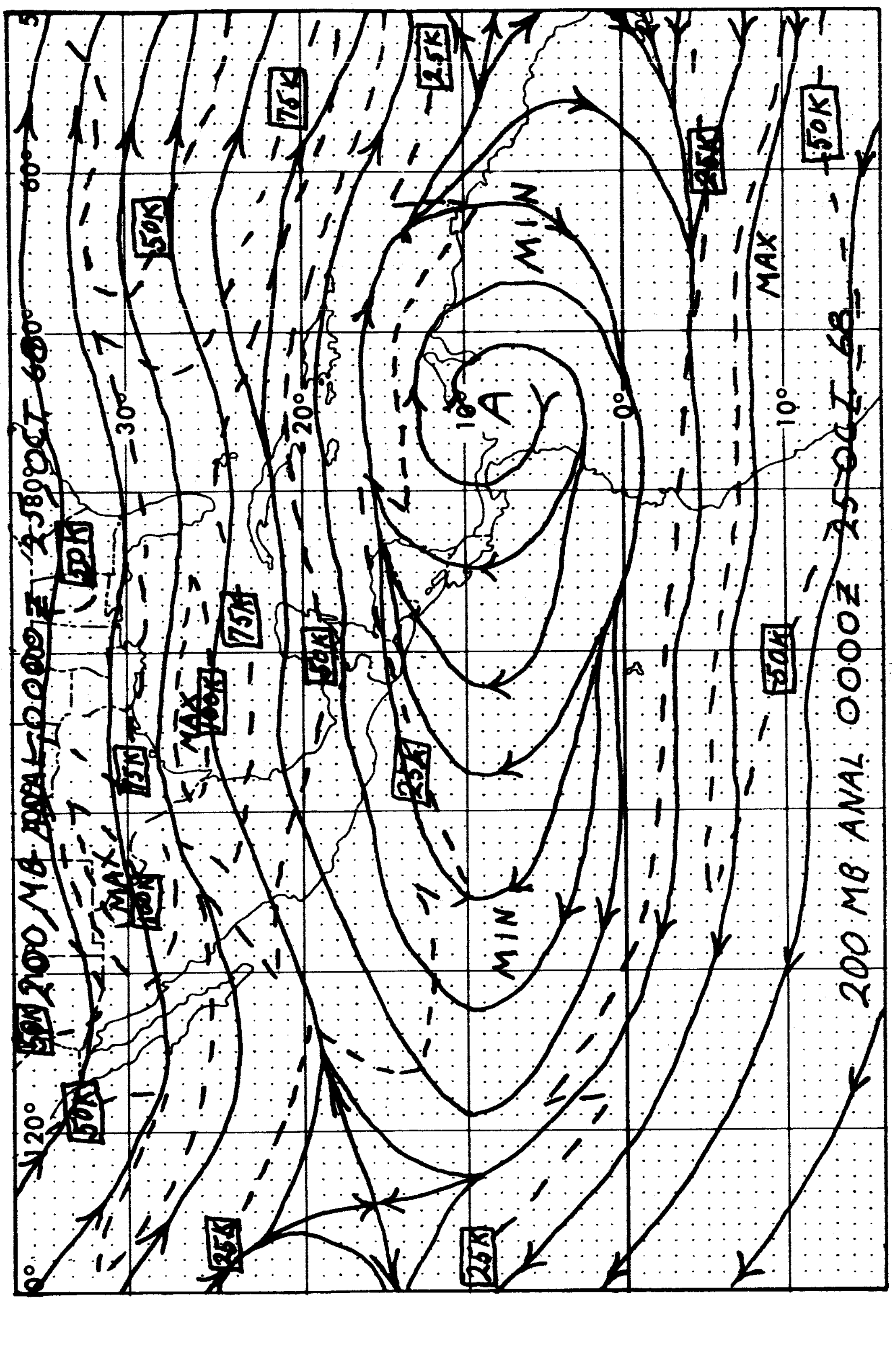

Figure 5-8 Tropical 200 mb Analysis (Streamlines and Isotachs)

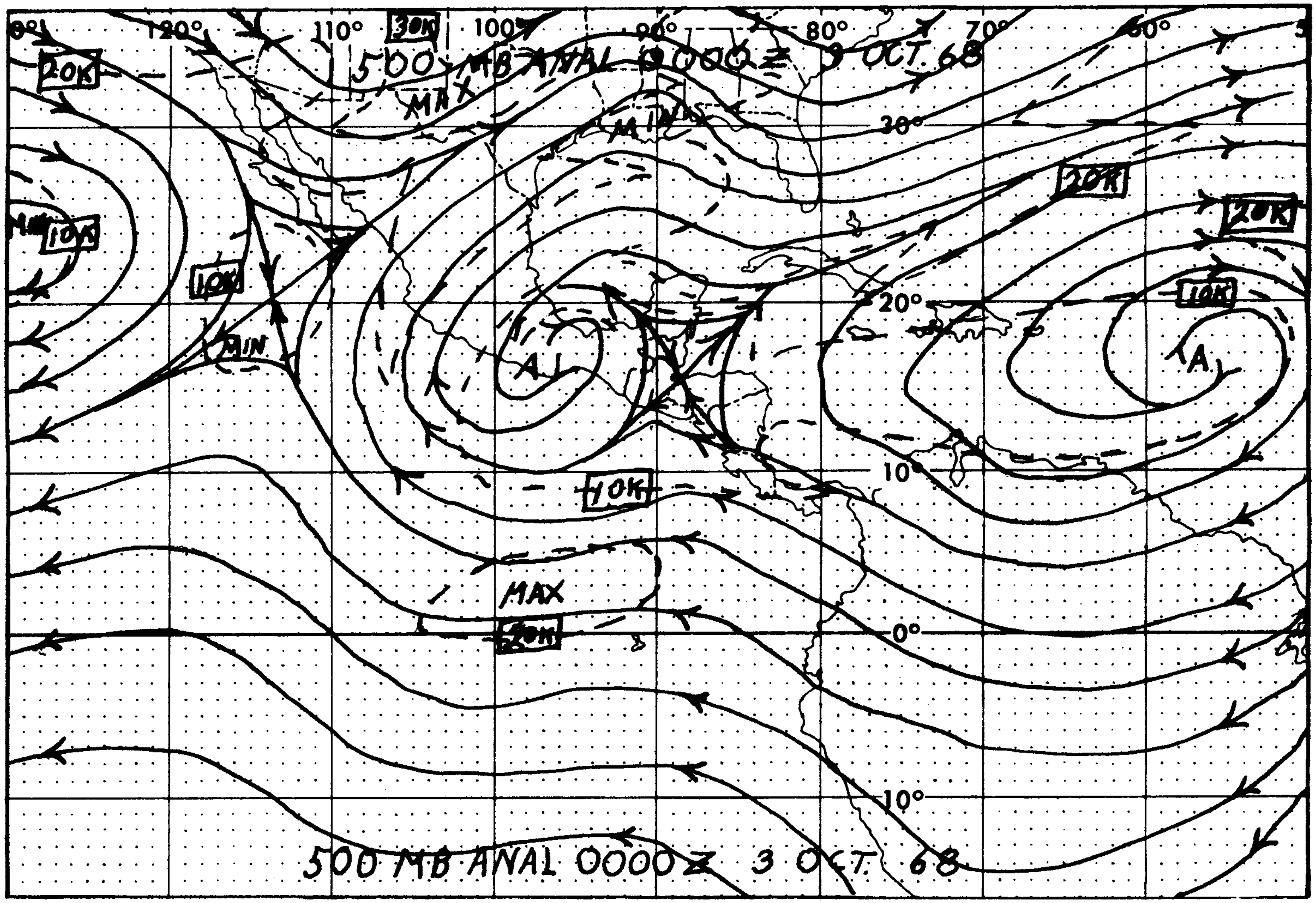

Figure 5-9 Tropical 500 mb Analysis (Streamlines and Isotachs)

6. SPECIFIC CHART SELECTIONS FOR SINGLE AND MULTIPLE SATELLITES

6.1 General Considerations

This section will deal with the specific selection of WEFAX charts to be transmitted from single and multiple satellite systems. The following systems of sun-synchronous and earth-synchronous satellites will be considered:

a. One earth-synchronous satellite, or three or four equally spaced earth-synchronous satellites.

b. One sun-synchronous satellite.

c. Two (or more) sun-synchronous satellites

d. One sun-synchronous satellite, and one or more earth-synchronous satellites.

The WEFAX chart recommendations listed below are based on the assumption that the very great majority of the APT stations have either (1) landline or radio weather facsimile and so essentially all the centrally prepared weather charts they most require (in any event many more than WEFAX is likely to provide in the near future); or (2) no source of centrally prepared weather charts, in which case their most urgent requirements are for the basic and most frequently used charts. An alternate approach, not considered in detail here, would be to assume that, since many of the present APT stations do have an adequate conventional facsimile capability, they would best be served (at least during the time the Nimbus D and ATS B satellites are expected to be operating) by the transmission of supplementary charts not normally available through conventional weather communications channels. Examples of such charts might include:

Large area, consolidated and annotated nephanalyses
Tropical weather depiction charts
10 mb analyses
30 day mean prognoses

Since the detail required by such charts would be no greater than for those illustrated in Section 5, they could readily be substituted, if so desired, for those listed below.

6.1.1 Assumptions

The assumptions which have been used in the subsequent analyses include:

a. The sun-synchronous satellites will be in nearly circular orbits at 750 n.mi.

b. The drift of the earth-synchronous satellites can be controlled.

c. The earth-synchronous and the sun-synchronous satellites will be transmitting on different frequencies.

In the case of concurrent APT and/or WEFAX transmissions from two or more sun-synchronous satellites, the polar convergence of the orbits increases the probability of having more than one satellite simultaneously within range of a station.* At best, this would mean stations would at times not be able to acquire the full transmission from both satellites. If both satellites used a common transmission frequency, the transmission near the pole from at least one of them would at times have to be temporarily and briefly curtailed to avoid interference.

For two satellites in an essentially common 750 n.mi. orbit, but with a steadily changing relative phasing in anomaly, the long term probability of at least some overlap of the areas of concurrently acquirable transmissions is about 30%. An overlap of one-third or greater will occur about 15% of the time, and one of one-half or greater about 10% of the time.

Applying these results to a TOS (0900 local time descending node) and a Nimbus (1200 local time ascending node) concurrently in orbit, we find:

Latitude	Approximate Probability of Overlap $\geq$ 0	1/3	1/2
0 to $\pm 2^{\circ}$	0%	0%	0%
$\pm 63^{\circ}$	30%	15%	10%
$\pm 90^{\circ}$	20%	10%	7%

* Any attempt to avoid this by phasing the relative positions of the satellites around their orbits (i.e., spacing in orbit anomaly) appears futile. To demonstrate this, consider two 750 n.mi. satellites in the same orbit, with one initially 180° in anomaly from the other. Assume the individual orbit periods of the two satellites vary by only 0.1 minute (a full minute would be far more realistic). Since the orbit period at 750 n.mi. is 113.4 minutes, in 567 orbits one satellite would have caught up with the other (i.e., no separation in anomaly). 567 orbits are completed in less than 45 days.

For two sun-synchronous satellites with ascending nodes 90° apart, the comparable data are:

Latitude	Approximate Probability of Overlap $\geq$		
	0	1/3	1/2
0 to $\pm 50^{\circ}$	0%	0%	0%
$\pm 75^{\circ}$	30%	15%	10%
$\pm 90^{\circ}$	20%	10%	7%

An analysis of the periods and areas of APT and/or WEFAX transmission overlap (or interference) will be required as a part of the detailed WEFAX programming whenever two or more sun-synchronous (or one or more sun-synchronous and earth-synchronous; see Section 6.5) satellites with APT and/or WEFAX systems are concurrently in operation. The variety of situations that could occur precludes a generalized analysis of the various possible alternatives in this report.

6.2 One (or More) Earth-Synchronous Satellites

The chart selections for one earth-synchronous satellite would also apply to the cases of two, three, or four earth-synchronous satellites,* as the only things affected are the specific geographical areas covered by the charts, and the stations which could receive the transmissions. In considering WEFAX transmissions from earth-synchronous satellites, we are assuming that WEFAX charts will be transmitted at approximately six-hour intervals, and that each six-hourly transmission period is limited to 20 minutes. If 25 minutes are available, the Southern Polar and Mid-latitude Chart would be sent in two sections rather than in one (see Section 4).

(The limitation to time of transmission imposed in this study is that for the ATS B, a single, multi-purpose, experimental earth-synchronous satellite. A multiple earth-synchronous satellite system with WEFAX capabilities would most probably be operational in character, with far greater - or possibly even full time - WEFAX transmissions. In such a case, the chart capability would approach or equal that on present landline or radio facsimile transmissions, as discussed in Section 2.5.)

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* Assuming, in the cases of three or four earth-synchronous satellites, they are approximately equally spaced in longitude.

6.2.1 First Transmission Period*

NPMW	Composite Surface & 500 Millibar Analysis
NPME	Composite Surface & 500 Millibar Analysis
TROP	Surface Analysis
SPM (or SPMW & SPME)	Composite Surface & 500 Millibar Analysis

6.2.2 Second Transmission Period

NPMW	Composite Surface & 500 Millibar 36 Hour Prognosis
NPME	Composite Surface & 500 Millibar 36 Hour Prognosis
TROP	200 Millibar Analysis
SPM(or SPMW & SPME)	Composite Surface & 500 Millibar 36 Hour Prognosis

6.2.3 Third and Fourth Transmission Periods

The transmissions in the third and fourth periods would be the same as those in the first and second periods, respectively, except that the times of the charts would be twelve hours later.

The above cycle would be repeated each day.

6.3 One Sun-Synchronous Satellite

The analysis of chart selections for the one sun-synchronous satellite case leads to the same types of charts being transmitted on each orbit in the middle latitudes.** In polar and tropical latitudes, the types of charts will alternate on every other orbit. The chart areas will change almost every orbit in tropical and mid-latitudes, and every other orbit in polar areas. The specific chart areas to be transmitted will depend, from a longitudinal viewpoint, upon the longitude of the ascending node, and can be determined from Table D-1 of Appendix D.

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* The designation of "first" is, of course, arbitrary. To the degree feasible, the scheduling of the transmissions should be phased with the availability from the NMC of the necessary analyses and prognoses.

** This redundancy derives from the recommendation as to longitudinal chart format discussed in Section 3.3.3.

Due to the amount of latitudinal and longitudinal overlap of the tropical chart areas, and to the reception in the tropics of a minimum of 1-1/2 WEFAX frames (3 charts) each day,* at least three types or levels of charts can be received by any tropical station by using the sequence and the orbital alternation of transmissions indicated below. Furthermore, due to the relatively large number of orbits acquirable by polar stations, mid-latitude as well as polar charts can be furnished to stations in the polar regions by using the sequence and the orbital alternations of transmissions indicated below. The chart selections are shown for two consecutive orbits (odd and even orbits), and the sequence of chart types is repeated every second orbit. The WEFAX frames are numbered here (and in Section 6.4) from north to south (rather than the reverse, south-to-north order in which they would be transmitted); this provides somewhat of a normal, map-oriented view of the charts transmitted, since listings in the south-to-north order are provided in the specific programs provided in Section 7.

* See Section 3.4.

6.3.1 Odd Orbits

Frame No.*	Chart Area	Type of Chart
1	Northern Polar	500 millibar Analysis
1	Northern Polar	Surface Analysis
2	Northern Mid-Latitude	36 Hour Surface & 500 millibar Prognosis
2	Northern Mid-Latitude	Surface & 500 millibar Analysis
3	Northern Tropical	Surface Analysis
3	Northern Tropical	500 millibar Analysis
4	Southern Tropical	200 millibar Analysis
4	Southern Tropical	Surface Analysis
5	Southern Mid-Latitude	Surface & 500 millibar Analysis
5	Southern Mid-Latitude	36 Hour Surface & 500 millibar Prognosis
6	Southern Polar	Surface Analysis
6	Southern Polar	500 millibar Analysis
7	Southern Mid-Latitude	Surface & 500 millibar Analysis
7	Southern Polar	36 Hour Surface & 500 millibar Prognosis

* Each numbered frame consists of one continuous, 8" x 11" WEFAX transmission, or two full charts.

6.3.2 Even Orbits

Frame No.	Chart Area	Type of Chart
1	Northern Mid-Latitude	Surface & 500 millibar Analysis
1	Northern Polar	36 Hour Surface & 500 millibar Prognosis
2	Northern Mid-Latitude	36 Hour Surface & 500 millibar Prognosis
2	Northern Mid-Latitude	Surface & 500 millibar Analysis
3	Northern Tropical	Surface Analysis
3	Northern Tropical	200 millibar Analysis
4	Southern Tropical	500 millibar Analysis
4	Southern Tropical	Surface Analysis
5	Southern Mid-Latitude	Surface & 500 millibar Analysis
5	Southern Mid-Latitude	36 Hour Surface & 500 millibar Prognosis
6	Southern Polar	36 Hour Surface & 500 millibar Prognosis
6	Southern Mid-Latitude	Surface & 500 millibar Analysis
7	Southern Polar	Surface Analysis
7	Southern Polar	500 millibar Analysis

6.4 Two (or More) Sun-Synchronous Satellites

The chart selections for two sun-synchronous satellites could be based on using the second satellite to provide either (1) up-dated data or (2) additional data, subject of course to the problem of possible interference near the poles (see Section 6. 1).

Since most meteorological charts are updated at 12 hourly intervals, the ideal situation would be WEFAX transmissions (for any given area) at intervals of approximately twelve hours, as is possible in the earth-synchronous case. For one or more sun-synchronous satellites, this is obviously not feasible unless night transmissions are to be employed (as in the absence of a DRIR capability). When two sun-synchronous APT satellites are concurrently in operation, it is most likely they will be in 0900-2100 and 0300-1500 (local time) orbits, or possibly in 0800-2000 and 0400-1600 orbits. For three concurrent satellites, the most likely orbit orientations will be 0800-2000, 1200-2400, and 0400-1600 (local time). These relative orbit orientations provide equal (or approximately equal) spacings of the satellite observations, in time, while avoiding the drastic illumination contrasts near the dawn-dusk line.

For two concurrent sun-synchronous satellites, this means that the (daylight) WEFAX transmissions will be at best only eight, and more likely only six, hours apart. Since the weather charts are at twelve hour intervals, and if it is assumed that the satellite sending the second set of transmissions (about 1500 or 1600 local time, the last before the long, over-night interval) would provide the latest analyses and prognoses available to it, the data from the first satellite (0800 or 0900) would often be rather old. This would be particularly true if the interval between the passes of the satellites over the same area is only six hours, or if the latest analyses or prognoses become available well before late afternoon, local time. Since observations are usually taken at fixed hours relative to Greenwich time (primarily 0000 and 1200), while the sun-synchronous satellite passes are related to local time, this second situation will inevitably occur over substantial areas of the world.

The better decision between the alternatives is far from obvious, and it may well be that trial runs of both alternates, followed by an evaluation of user responses, may be in order before a final decision can be reached. It may also be that updating will be the better course in those areas where recent charts become available shortly before the afternoon passes; in other areas, where the data on the morning passes would then necessarily be rather old (especially where recent data become available shortly before the morning passes) supplementary additional data on one of the two sets of passes may be the optimum choice.

In any event, if the decision (whether for any areas or all areas) is to furnish 12 hourly updated charts, both satellites would furnish the charts listed in Section 6.3, but with the charts for each satellite (in turn) being 12 hours later than those for the other.

If the decision is to provide additional charts (again, either for any or all areas), one satellite would transmit the charts previously listed in Section 6.3 (which one depending on which can provide the most recent analyses or prognoses), while the other would provide the charts listed in Sections 6.4.1 and 6.4.2 below.

If three sun-synchronous satellites are concurrently in operation, it is suggested that two (probably the earliest and the latest each day, local dayside time) provide the charts listed in Section 6.3, while the third satellite (probably that nearest local noon, but again considering the times at which specific charts become available) provide the charts listed in Sections 6.4.1 and 6.4.2.

If it is decided, considering the factors discussed above, to furnish additional charts (thereby supply the forecaster with more types of information), it is recommended that the charts and their sequences be those listed below. (In those instances where a 72 hour surface prognosis is indicated in the listings, the 5-day surface prognosis could be substituted on the three days each week that it is available):

6.4.1 Odd Orbits

Frame No.	Chart Area	Type of Chart
1	Northern Polar	72 Hour Surface Prognosis
1	Northern Polar	200 millibar Analysis
2	Northern Mid-Latitude	72 Hour Surface Prognosis
2	Northern Mid-Latitude	200 millibar Analysis
3	Northern Tropical	36 Hour Surface Prognosis
3	Northern Tropical	700 millibar Analysis
4	Southern Tropical	850 millibar Analysis
4	Southern Tropical	36 Hour Surface Prognosis
5	Southern Mid-Latitude	200 millibar Analysis
5	Southern Mid-Latitude	72 Hour Surface Prognosis
6	Southern Polar	200 millibar Analysis
6	Southern Polar	72 Hour Surface Prognosis
7	Southern Mid-Latitude	200 millibar Analysis
7	Southern Polar	300 millibar Analysis

6.4.2 Even Orbits

Frame No.	Chart Area	Type of Chart
1	Northern Mid-Latitude	36 Hour Surface & 500 millibar Prognosis
1	Northern Polar	300 millibar Analysis
2	Northern Mid-Latitude	72 Hour Surface Prognosis
2	Northern Mid-Latitude	200 millibar Analysis
3	Northern Tropical	36 Hour Surface Prognosis
3	Northern Tropical	850 millibar Analysis
4	Southern Tropical	700 millibar Analysis
4	Southern Tropical	36 Hour Surface Prognosis
5	Southern Mid-Latitude	200 millibar Analysis
5	Southern Mid-Latitude	72 Hour Surface Prognosis
6	Southern Polar	300 millibar Analysis
6	Southern Mid-Latitude	200 millibar Analysis
7	Southern Polar	200 millibar Analysis
7	Southern Polar	72 Hour Surface Prognosis

6.5 One Sun-Synchronous Satellite and One (or More) Earth-Synchronous Satellite

When there are both an earth-synchronous satellite and a sun-synchronous satellite concurrently in operation, the chart selection for the sun-synchronous should remain the same as in Section 6.3; the earth-synchronous satellite should be used to furnish other types of charts in the daytime, and to up-date the sun-synchronous charts during the nighttime.* It is assumed, for convenience, that the transmissions from the earth-synchronous satellite will be made the satellite's local times of 0300, 0900, 1500, and 2100,** thereby providing the area of reception with two daytime and two nighttime transmissions. In order to provide a minimum amount of interference between the reception of the transmissions from the two satellites, the transmissions from the earth-synchronous satellite should, if at all feasible, be made when the sun-synchronous satellite is on the opposite side of the earth. If this is not possible, the earth-synchronous northern chart areas should be transmitted while the sun-synchronous satellite is in the Southern Hemisphere, and the earth-synchronous southern chart areas while the sun-synchronous satellite is in the Northern Hemisphere.

The areas of reception of the transmissions from an earth-synchronous satellite and any single 750 n.mi. sun-synchronous satellite will at least partially overlap for a total of about 4 1/2 hours during a 12 hour period. There will, however, be an interval without interference, during each orbit, which will be at least one-half the period of the sun-synchronous orbit in length.

6.5.1 The Sun-Synchronous Satellite Transmissions

The charts transmitted by the sun-synchronous satellite should be the same as those indicated in Section 6.3.

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* Again, as discussed at the beginning of Section 6.2, these findings are also valid for more than one earth-synchronous satellite, assuming little or no overlap of the areas of reception.

** The specific times, under actual operational conditions, should be synchronized with the local times of chart availability.

6.5.2 Nighttime Earth-Synchronous Satellite Transmissions, When a Sun-Synchronous Satellite is Operating Concurrently

The charts transmitted by the earth-synchronous satellite during the nighttime periods (2100 and 0300) should be the same as those indicated in Sections 6.2.1 and 6.2.2.

6.5.3 Daytime Earth-Synchronous Satellite Transmissions, When a Sun-Synchronous Satellite is Operating Concurrently

6.5.3.1 First Transmission Period (0900)

NPMW	200 millibar Analysis
NPME	200 millibar Analysis
TROP	700 millibar Analysis
SPM(or SPMW & SPME)	200 millibar Analysis

6.5.3.2 Second Transmission Period (1500)

NPMW	72 Hour Surface Prognosis
NPME	72 Hour Surface Prognosis
TROP	36 Hour Surface Prognosis
SPM(or SPMW & SPME)	72 Hour Surface Prognosis

The cases for more than one sun-synchronous satellite, operating concurrently with one (or more) earth-synchronous satellites, are obviously more complex. Since such a situation is unlikely to occur for some years, it seems justified to postpone its specific consideration until actual experience with one or more of the cases discussed above can be obtained and applied.

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7. SAMPLE PROGRAMS

7.1 General Considerations

The sample programs presented here are for the following cases:

a. One earth-synchronous satellite.
b. One sun-synchronous satellite.
c. Two sun-synchronous satellites.
d. One earth-synchronous satellite and one sun-synchronous satellite.

The ease with which these programs can be generalized to other and/or more complex cases should be obvious from the discussions in the previous sections.

The earth-synchronous satellite programs are for a satellite at a height of approximately 19,250 n. mi., and located above the equator at 155 degrees west longitude. The program is based on twenty minutes of transmission every six hours, and with the WEFAX transmissions assumed for convenience to start at 0300, 0900, 1500, and 2100 local satellite time. The chart areas are those specified in Section 4, and the types of charts are those discussed in Section 5 and specified in Section 6.

The sun-synchronous satellite programs are for a Nimbus type satellite, with a near circular orbit and a height of 750 n. mi. The programs will again be based on an APT picture every 8.05 minutes, arranged so that one of the APT pictures is taken exactly at the ascending node time. WEFAX transmissions will be limited to the daytime, and will be programmed between the APT picture transmissions. The program times are presented in terms of minutes and seconds before and after ascending node. The chart areas are those specified in Section 3, and the types of charts are those discussed in Section 5 and specified in Section 6.

7.2 Program For One Earth-Synchronous Satellite

Transmission Time From	To	Chart Area	TYPE OF CHART
0300:00	0304:10	NPMW	Surface & 500 mb Analysis
0304:10	0308:20	NPME	Surface & 500 mb Analysis
0308:20	0316:40	TROP	Surface Analysis
0316:40	0320:00	SPM*	Surface & 500 mb Analysis
0900:00	0904:10	NPMW	Surface & 500 mb 36 Hour Prognosis
0904:10	0908:20	NPME	Surface & 500 mb 36 Hour Prognosis
0908:20	0916:40	TROP	200 mb Analysis
0916:40	0920:00	SPM*	Surface & 500 mb 36 Hour Prognosis
1500:00	1504:10	NPMW	Surface & 500 mb Analysis
1504:10	1508:20	NPME	Surface & 500 mb Analysis
1508:20	1516:40	TROP	Surface Analysis
1516:40	1520:00	SPM*	Surface & 500 mb Analysis
2100:00	2104:10	NPMW	Surface & 500 mb 36 Hour Prognosis
2104:10	2108:20	NPME	Surface & 500 mb 36 Hour Prognosis
2108:20	2116:40	TROP	200 mb Analysis
2116:40	2120:00	SPM*	Surface & 500 mb 36 Hour Prognosis

7.3 Program For One Sun-Synchronous Satellite

The sample program has been prepared for an ascending node of the first orbit at 80°W longitude, and that of the second orbit at 108.35°W longitude.

* The use of the alternate SPMW and SPME charts would require extending each transmission period by another five minutes.

a. First Orbit

Transmission Time (Mins & Sec from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
-28:43	-26:26.5	SP60W	Surface & 500 mb 36 Hour Prognosis
-26:26.5	-24:09	SM60W	Surface & 500 mb Analysis
-24:09	-20:41		APT Picture
-20:41	-18:23.5	SP60W	500 mb Analysis
-18:23.5	-16:06	SP60W	Surface Analysis
-16:06	-12:38		APT Picture
-12:38	-10:20.5	SM60W	Surface & 500 mb 36 Hour Prognosis
-10:20.5	- 8:03	SM60W	Surface & 500 mb Analysis
- 8:03	- 4:35		APT Picture
- 4:35	- 2:17.5	ST90W	Surface Analysis
- 2:17.5	0	ST90W	200 mb Analysis
0	+ 3:28		APT Picture
+ 3:28	+ 5:45.5	NT90W	500 mb Analysis
+ 5:45.5	+ 8:03	NT90W	Surface Analysis
+ 8:03	+11:31		APT Picture
+11:31	+13:48.5	NM90W	Surface & 500 mb Analysis
+13:48.5	+16.06	NM90W	Surface & 500 mb 36 Hour Prognosis
+16:06	+19:34		APT Picture
+19:34	+21:51.5	NP120W	Surface Analysis
+21:51.5	+24:09	NP120W	500 mb Analysis
+24:09	+27:37		APT Picture

b. Second Orbit

Transmission Time (Mins & Secs from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
-28:43	-26:26.5	SP60W	500 mb Analysis
-26:26.5	-24:09	SP60W	Surface Analysis
-24:09	-20:41		APT Picture
-20:41	18:23.5	SM90W	Surface & 500 mb Analysis

Cont'd

Transmission Time (Mins & Secs from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
-18:23.5	-16:06	SP60W	Surface & 500 mb 36 Hour Prognosis
-16:06	-12:38		APT Picture
-12:38	-10:20.5	SM90W	Surface & 500 mb 36 Hour Prognosis
-10:20.5	- 8:03	SM90W	Surface & 500 mb Analysis
- 8:03	- 4:35		APT Picture
- 4:35	- 2:17.5	ST120W	Surface Analysis
- 2:17.5	0	ST120W	500 mb Analysis
0	+ 3:28		APT Picture
+ 3:28	+ 5:45.5	NT120W	200 mb Analysis
+ 5:45.5	+ 8:03	NT120W	Surface Analysis
+ 8:03	+11:31		APT Picture
+11:31	+13:48.5	NM120W	Surface & 500 mb Analysis
+13:48.5	+16.06	NM120W	Surface & 500 mb 36 Hour Prognosis
+16:06	+19:34		APT Picture
+19:34	+21:51.5	NP120W	Surface & 500 mb 36 Hour Prognosis
+21:51.5	+24:09	NM120W	Surface & 500 mb Analysis
+24:09	+27:37		APT Picture

7.4 Program For Two Sun-Synchronous Satellites

In the case of two sun-synchronous satellites, it has been assumed here that the alternative (see Section 6.4) of providing additional types of charts has been chosen. The program for the first satellite of the day would then be the same as that in Section 7.3, for one sun-synchronous satellite. The program for the second satellite assumes an ascending node on the first orbit at 75°W longitude, and an ascending node on the second orbit at 103.35°W longitude.

a. First Orbit

Transmission Time (Mins & Secs from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
-28:43	-26:26.5	SP60W	300 mb Analysis
-26:26.5	-24:09	SM60W	200 mb Analysis
-24:09	-20:41		APT Picture

Cont'd

Transmission Time (Mins & Secs from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
-20:41	-18:23.5	SP60W	72 Hour Surface Prognosis
-18:23.5	-16:06	SP60W	200 mb Analysis
-16:06	-12:38		APT Picture
-12:38	-10:20.5	SM60W	72 Hour Surface Prognosis
-10:20.5	- 8:03	SM60W	200 mb Analysis
- 8:03	- 4:35		APT Picture
- 4:35	- 2:17.5	ST60W	Surface 36 Hour Prognosis
- 2:17.5	0	ST60W	850 mb Analysis
0	+ 3:28		APT Picture
+ 3:28	+ 5:45.5	NT90W	700 mb Analysis
+ 5:45.5	+ 8:03	NT90W	Surface 36 Hour Prognosis
+ 8:03	+11:31		APT Picture
+11:31	+13:48.5	NM90W	200 mb Analysis
+13:48.5	+16:06	NM90W	72 Hour Surface Prognosis
+16:06	+19:34		APT Picture
+19:34	+21:51.5	NP120W	200 mb Analysis
+21:51.5	+24:09	NP120W	72 Hour Surface Prognosis
+24:09	+27:37		APT Picture

b. Second Orbit

Transmission Time (Mins & Secs from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
-28:43	-26:26.5	SP60W	Surface 72 Hour Prognosis
-26:26.5	-24:09	SP60W	200 mb Analysis
-24:09	-20:41		APT Picture
-20:41	-18:23.5	SM90W	200 mb Analysis
-18:23.5	-16:06	SP60W	300 mb Analysis
-16:06	-12:38		APT Picture
-12:38	-10:20.5	SM90W	Surface 72 Hour Prognosis
-10:20.5	- 8:03	SM90W	200 mb Analysis
- 8:03	- 4:35		APT Picture
- 4:35	- 2:17.5	ST90W	Surface 36 Hour Prognosis
- 2:17.5	0	ST90W	700 mb Analysis

Cont'd

Transmission Time (Mins & Secs from Ascend. Node) From	To	Chart Area	TYPE OF TRANSMISSION
0	+ 3:28		APT Picture
+ 3:28	+ 5:45.5	NT120W	850 mb Analysis
+ 5:45.5	+ 8:03	NT120W	Surface 36 Hour Prognosis
+ 8:03	+11:31		APT Picture
+11:31	+13:48.5	NM120W	200 mb Analysis
+13:48.5	+16:06	NM120W	Surface 72 Hour Prognosis
+16:06	+19:34		APT Picture
+19:34	+21:51.5	NP120W	300 mb Analysis
+21:51.5	+24:09	NM120W	Surface & 500 mb 36 Hour Prognosis
+24:09	+27:37		APT Picture

7.5 Program for One Earth-Synchronous Satellite and One Sun-Synchronous Satellite

With both an earth-synchronous satellite and a sun-synchronous satellite concurrently in operation, the program for the sun-synchronous satellite would be the same as that in Section 7.3, for one sun-synchronous satellite. The program for the earth-synchronous would be as follows:

Transmission Time From	To	Chart Area	TYPE OF CHART
0300:00	0304:10	NPMW	Surface & 500 mb Analysis
0304:10	0308:20	NPME	Surface & 500 mb Analysis
0308:20	0316:40	TROP	Surface Analysis
0316:40	0320:00	SPM*	Surface & 500 mb Analysis
0900:00	0904:10	NPMW	200 mb Analysis
0904:10	0908:20	NPME	200 mb Analysis
0908:20	0916:40	TROP	700 mb Analysis
0916:40	0920:00	SPM*	200 mb Analysis
1500:00	1504:10	NPMW	Surface 72 Hour Prognosis
1504:10	1508:20	NPME	Surface 72 Hour Prognosis
1508:20	1516:40	TROP	Surface 36 Hour Prognosis
1516:40	1520:00	SPM*	Surface 72 Hour Prognosis

* See footnote to Section 7.2.

Cont'd

Transmission Time From	To	Chart Area	TYPE OF CHART
2100:00	2104:10	NPMW	Surface & 500 mb 36 Hour Prognosis
2104:10	2108:20	NPME	Surface & 500 mb 36 Hour Prognosis
2108:20	2116:40	TROP	200 mb Analysis
2116:40	2120:00	SPM*	Surface & 500 mb 36 Hour Prognosis

7.6 WEFAX Chart Reception from Proposed Programs

Programs of the types proposed above provide sufficient weather charts to all stations, regardless of geographical locations. The average daily reception of stations at various typical latitudes is shown in Tables 7-1 through 7-7.

* See footnote to Section 7.2.

Table 7-1

Average Number and Types of Weather Charts Received Daily by a Station 60°N Latitude

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

TWO-SUN SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
3	NP	500 Anal
2	NP	Sfc Anal
2	NP	Sfc & 500 36 Hr. Prog
3	NP	Sfc 72 Hr Prog
2	NP	200 Anal
2	NP	300 Anal
3	NM	Sfc & 500 Anal
3	NM	Sfc & 500 36 Hr Prog
2	NM	Sfc 72 Hr Prog
2	NM	200 Anal

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
3	NP	500 Anal
2	NP	Sfc Anal
2	NP	Sfc & 500 36 Hr Prog
3	NM	Sfc & 500 Anal
3	NM	Sfc & 500 36 Hr Prog

ONE EARTH-SYNCHRONOUS SATELLITE & ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
3	NP	500 Anal
2	NP	Sfc Anal
2	NP	Sfc & 500 36 Hr Prog
3	NM	Sfc & 500 Anal
3	NM	Sfc & 500 36 Hr Prog
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

Table 7-2

Average Number and Types of Weather Charts
Received Daily by a Station at 40°N Latitude

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
½	NP	Sfc Anal
½	NP	Sfc & 500 36 Hr Prog
3	NM	Sfc & 500 Anal
3	NM	Sfc & 500 36 Hr Prog
1	NT	Sfc Anal
½	NT	200 (or 500) Anal

TWO-SUN SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
½	NP	Sfc Anal
½	NP	200 Anal
½	NP	Sfc & 500 36 Hr Prog
½	NP	300 Anal
3	NM	Sfc & 500 36 Hr Prog
3	NM	Sfc 72 Hr Prog
3	NM	Sfc & 500 Anal
3	NM	200 Anal
1	NT	Sfc Anal
1	NT	Sfc 36 Hr Prog
½	NT	200 (or 500) Anal
½	NT	700 (or 850) Anal

ONE EARTH-SYNCHRONOUS SATELLITE & ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
½	NP	Sfc Anal
½	NP	Sfc & 500 36 Hr Prog
3	NM	Sfc & 500 Anal
3	NM	Sfc & 500 36 Hr Prog
1	NT	Sfc Anal
½	NT	200 (or 500) Anal
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

Table 7-3

Average Number and Types of Weather Charts
Received Daily by a Station at 20°N Latitude

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
1	NM	Sfc & 500 Anal
½	NM	Sfc & 500 36 Hr Prog
2	NT	Sfc Anal
1	NT	200 Anal
1	NT	500 Anal
½	ST	200 (or 500) Anal

TWO SUN-SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
1	NM	Sfc & 500 Anal
1	NM	200 Anal
½	NM	Sfc & 500 36 Hr Prog
½	NM	Sfc 72 Hr Prog
2	NT	Sfc Anal
2	NT	Sfc 36 Hr Prog
1	NT	200 Anal
1	NT	850 Anal
1	NT	500 Anal
1	NT	700 Anal
½	ST	200 (or 500) Anal
½	ST	850 (or 700) Anal

ONE-EARTH-SYNCHRONOUS SATELLITE &
ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
1	NM	Sfc & 500 Anal
½	NM	Sfc & 500 36 Hr Prog
2	NT	Sfc Anal
1	NT	200 Anal
1	NT	500 Anal
½	ST	200 (or 500) Anal
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

Table 7-4

Average Number and Types of Weather Charts Received Daily by a Station at 0^{o} Latitude

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
1	NT	Sfc Anal
1	NT	500 Anal
1	NT	200 Anal
1	ST	200 Anal
1	ST	500 Anal
1	ST	Sfc Anal

TWO SUN-SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
1	NT	Sfc Anal
1	NT	Sfc 36 Hr Prog
1	NT	500 Anal
1	NT	700 Anal
1	NT	200 Anal
1	NT	850 Anal
1	ST	850 Anal
1	ST	200 Anal
1	ST	700 Anal
1	ST	500 Anal
1	ST	Sfc 36 Hr Prog
1	ST	Sfc Anal

ONE EARTH-SYNCHRONOUS SATELLITE & ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
1	NT	Sfc Anal
1	NT	500 Anal
1	NT	200 Anal
1	ST	200 Anal
1	ST	500 Anal
1	ST	Sfc Anal
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

Table 7-5

Average Number and Types of Weather Charts Received Daily by a Station at 20°S Latitude

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
1	ST	200 Anal
1	ST	500 Anal
2	ST	Sfc Anal
2	SM	Sfc & 500 Anal
2	SM	Sfc & 500 36 Hr Prog

TWO SUN-SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
1	ST	200 Anal
1	ST	850 Anal
1	ST	500 Anal
1	ST	700 Anal
2	ST	Sfc Anal
2	ST	Sfc 36 Hr Prog
2	SM	Sfc & 500 Anal
2	SM	200 Anal
2	SM	Sfc & 500 36 Hr Prog
2	SM	Sfc 72 Hr Prog

ONE EARTH-SYNCHRONOUS SATELLITE & ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
1	ST	200 Anal
1	ST	500 Anal
2	ST	Sfc Anal
2	SM	Sfc & 500 Anal
2	SM	Sfc & 500 36 Hr Prog
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

Table 7-6

Average Number and Types of Weather Charts Received Daily by a Station at 40°S Latitude.

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
2	SM	Sfc & 500 Anal
3	SM	Sfc & 500 36 Hr Prog
1	SP	Sfc Anal
1	SP	Sfc & 500 36 Hr Prog
1	SP	500 Anal

TWO SUN-SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
2	SM	Sfc & 500 Anal
2	SM	200 Anal
3	SM	Sfc & 500 36 Hr Prog
3	SM	Sfc 72 Hr Prog
1	SP	Sfc Anal
1	SP	200 Anal
1	SP	Sfc & 500 36 Hr Prog
1	SP	300 Anal
1	SP	500 Anal
1	SP	Sfc 72 Hr Prog

ONE EARTH-SYNCHRONOUS SATELLITE & ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
2	SM	Sfc & 500 Anal
3	SM	Sfc & 500 36 Hr Prog
1	SP	Sfc Anal
1	SP	Sfc & 500 36 Hr Prog
1	SP	500 Anal
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

Table 7-7

Average Number and Types of Weather Charts
Received Daily by a Station at 60°S Latitude

ONE EARTH-SYNCHRONOUS SATELLITE

Number of Different Periods	Chart Area	Type of Chart
2	NPMW	Sfc & 500 Anal
2	NPMW	Sfc & 500 36 Hr Prog
2	NPME	Sfc & 500 Anal
2	NPME	Sfc & 500 36 Hr Prog
2	TROP	Sfc Anal
2	TROP	200 Anal
2	SPM	Sfc & 500 Anal
2	SPM	Sfc & 500 36 Hr Prog

ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas	Chart Area	Type of Chart
2	SP	Sfc Anal
2	SP	500 Anal
3	SP	Sfc & 500 36 Hr Prog
4	SM	Sfc & 500 Anal
1	SM	Sfc & 500 36 Hr Prog

TWO SUN-SYNCHRONOUS SATELLITES

Number of Different Areas or Periods	Chart Area	Type of Chart
2	SP	Sfc Anal
2	SP	200 Anal
2	SP	500 Anal
2	SP	Sfc 72 Hr Prog
3	SP	Sfc & 500 36 Hr Prog
3	SP	300 Anal
4	SM	Sfc & 500 Anal
4	SM	200 Anal
1	SM	Sfc & 500 36 Hr Prog
1	SM	Sfc 72 Hr Prog

ONE EARTH-SYNCHRONOUS SATELLITE &
ONE SUN-SYNCHRONOUS SATELLITE

Number of Different Areas or Periods	Chart Area	Type of Chart
2	SP	Sfc Anal
2	SP	500 Anal
3	SP	Sfc & 500 36 Hr Prog
4	SM	Sfc & 500 Anal
1	SM	Sfc & 500 36 Hr Prog
1	NPMW	Sfc & 500 Anal
1	NPMW	Sfc & 500 36 Hr Prog
1	NPMW	200 Anal
1	NPMW	Sfc 72 Hr Prog
1	NPME	Sfc & 500 Anal
1	NPME	Sfc & 500 36 Hr Prog
1	NPME	200 Anal
1	NPME	Sfc 72 Hr Prog
1	TROP	Sfc Anal
1	TROP	200 Anal
1	TROP	700 Anal
1	TROP	Sfc 36 Hr Prog
1	SPM	Sfc & 500 Anal
1	SPM	Sfc & 500 36 Hr Prog
1	SPM	200 Anal
1	SPM	Sfc 72 Hr Prog

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

This study has shown that the transmission of facsimile weather charts by the use of the APT system (WEFAX) is both entirely feasible and highly desirable. There are a significant number of weather stations already equipped with APT receivers and so able to receive the weather charts, and more APT sets can be expected to be installed within the foreseeable future. Regardless of the geographical location of a station, it will be able to receive a significantly useful number and variety of WEFAX charts. The greatest value of the WEFAX data will, of course, be to those stations and in those areas where conventional weather communications are marginal or inadequate.

The study has shown that the minimum orbit altitude at which a sun-synchronous satellite can provide a useful number and variety of WEFAX charts is approximately 750 n. mi. The programming of the charts would be relatively simple, and can readily be arranged and optimized so that weather stations in all areas would receive significant benefits. The programming of multiple satellite systems is slightly more complex, but the additional numbers and varieties of charts which could be transmitted by multiple satellite systems more than compensates for the additional effort.

The basic capability of a WEFAX system could, of course, be used to transmit a wide variety of other types of graphic material provided that (1) the scanner unit has an appropriate gray scale capability, (2) the material can be fitted into the available transmission (and recording) areas, and (3) the sizes of alphanumeric or other characters are large enough to be readable after scanning, transmission, and recording. This capability might, for example, be used to disseminate instructions or programs relating to WEFAX tests or operations.

8.2 Recommendations

This study has been as complete as seems merited at this stage of the development of a WEFAX capability; it could, if necessary, be used as the direct basis for implementing a WEFAX test program. There are still, however, a number of subsidiary further investigations and specific preparations that should, if at all possible, be carried out prior to any actual WEFAX test or operational program.

The specific preparations recommended include:

1. Preparation of the required base maps for the various recommended chart areas, to be drafted and printed in the proper scales and projections.

2. Determination as to whether the applicable NMC analyses are presently produced at the identical scales at which WEFAX transmission is contemplated. (Although standard NMC scales and projections have been adopted for WEFAX, these may not be the scales and projections at which various of the analyses and prognoses are presently produced.) If frequent scale transformations will be necessary when preparing the WEFAX charts, a camera lucida or equivalent device for simplying the transformation (usually scale reduction) should be obtained.

3. Preparation, publication, and dissemination of a User's Guide to WEFAX, which should include such items as (1) chart areas and types, (2) codes and symbols to be used, (3) sample transmission programs (for a nominal orbit), and (4) methods by which individual stations can determine exactly what charts they can acquire, and when.

4. Establishment, and manning, adequately in advance of satellite launch, of the unit which will be responsible for programming the WEFAX transmissions, obtaining the required analyses and prognoses from NMC, preparing the specific WEFAX charts to be transmitted, and dispatching them to the DAF (or to their interface with the DAF).

During the period between establishment of the unit and WEFAX satellite launch, such a unit would be fully occuppied with training of the assigned personnel. Part of this training must consist of an extensive dry run, during which actual chart acquisitions, preparations, and transmissions should be simulated on a real time, operational basis (preferably using actual charts for the dates over which the simulation program is conducted). Such a simulation provides the only sure way of eliminating from the system, well prior to launch, such unforeseen deficiencies as will almost inevitably exist (regardless of how extensively the system has been studied and designed).

As a by-product of the early phases of this simulation, the following matters should be investigated more fully than was feasible in the necessarily generalized, and somewhat idealized, studies and program formulations discussed and presented in this report:

1. Any program rearrangements, adjustments, or even chart substitutions that may be desirable, from one geographical area to another, as a consequence of the relationships between the times of chart availability (fixed time relative to GMT),

and the WEFAX transmission deadlines (fixed local times relative to the areas of satellite transmissions).

2. Any program adjustments that may be desirable, from time to time, as a consequence of the non-integral number of daily sun-synchronous orbits.

3. Any desirable minor modifications to the charts specified for transmission, as a function of ascending node longitude, in Appendix D. The object of any such changes would be to optimize the chart coverages, as a function of receiving station locations, in accordance with the criteria stated in Section 3.3.

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APPENDIX A
LOCATIONS OF APT STATIONS

The following is a list of APT stations with their approximate locations. This list includes both those which are known to be presently in existence, and those which are known to be planned for installation within the next year. All stations listed are normal, fixed stations unless indicated as remote * or mobile. Where known, the agency responsible for the operation of the APT set is also indicated. In some cases the specific location of the APT set could not be obtained, so an approximate location has been given. This list is based on data available as of about October 1965.

UNITED STATES (Contiguous 48 states)	Lat Deg	Lat Min	Long Deg	Long Min
Weather Bureau				
Albuquerque, N. M.	33	05N	106	38W
Boston, Mass.	42	20	71	05
Chicago, Ill.	41	50	87	45
Denver, Colo.	39	45	105	00
Great Falls, Mont.	47	30	111	16
Kansas City, Mo.	39	02	94	33
Los Angeles, Calif.	34	00	118	15
Miami, Fla.	25	45	80	15
New Orleans, La.	30	00	90	03
New York, N. Y.	40	40	73	50
Salt Lake City, Utah	40	45	111	55
San Francisco, Calif.	37	45	122	27
Seattle, Wash.	47	35	122	20
Suitland, Md.	38	51	76	55
Air Force				
Andrews AFB, Md. (Remote)	38	51N	76	55W
Barksdale AFB, La. (Remote)	32	31	93	44
Chanute AFB, Ill.	40	18	88	11
Charleston AFB, S. C. (Mobile)	32	48	79	58

* A remote station is one operating only a facsimile recorder tied to another APT set.

UNITED STATES (Cont.)

Air Force (Cont.)

Ent AFB, Colo.	38 50N	104 50W
Langley AFB, Va.	37 02	76 21
MacDill AFB, Fla. (Mobile)	27 58	82 38
March AFB, Calif. (Remote)	33 59	117 22
Offutt AFB, Neb.	41 15	96 00
Patrick AFB, Fla. (Remote)	28 28	80 28
Scott AFB, Ill. (Remote)	38 31	89 59
Vandenberg AFB, Calif.	34 35	120 38
Westover AFB, Mass.	42 09	72 37
AFCRL, Cambridge, Mass. (Research)	42 22	71 06
Keesler AFB, Miss. (Training)	30 24	88 55

Navy

Alameda, Calif. (Remote)	37 44N	122 14W
Jacksonville, Fla.	30 20	81 40
Lakehurst, N. J.	40 01	74 19
Monterey, Calif.	36 35	121 55
Norfolk, Va. (Remote)	36 54	76 18
Point Mugu, Calif.	34 08	119 05
Quonset Point, R. I. (Remote)	41 36	71 25
San Diego, Calif. (Remote)	32 45	117 10
Suitland, Md. (Remote)	38 51	76 55
Two ships in Atlantic		
Two ships in Pacific		

Army

Fort Monmouth, N. J.	40 18N	74 02W

NASA

Goddard Space Flight Center, Md.	39 00N	76 53W
Wallops Island, Va.	37 55	75 23
Fairchild-Stratos, Bay Shore, L. I., N. Y.	40 43	73 15
General Electric, Valley Forge, Pa.	40 06	75 27
RCA/AED, Princeton, N. J.	40 21	74 40

UNITED STATES (Cont.)

Private Users

Andrews, G. F., Miami, Fla.	24 45N	80 15W
Bendix Corp., Ann Arbor, Mich.	42 18	83 43
Boeing Co., Huntsville, Ala.	34 44	86 35
Calif. Computer Products, Anaheim, Calif.	33 50	117 56
Kline, J. F., Royal Oak, Mich.	42 31	83 08
KZTV, Corpus Christi, Texas	27 47	97 26
Scientific Atlanta, Inc., Atlanta, Ga.	33 45	84 23
So. Dak. Sch. of Mines & Tech., Rapid City, S. D.	44 06	103 14
Univ. of Michigan, Ann Arbor, Mich.	42 18	83 43
Univ. of Wisconsin, Madison, Wisc.	43 04	89 22
Western Ky. State College, Bowling Green, Ky.	37 00	86 29
WLAC-TV, Nashville, Tenn.	36 10	86 50
WSM-TV, Nashville, Tenn.	36 10	86 50

ALASKA

Adak, Aleutian Islands (USN)	51 52N	176 40W
Elmendorf AFB, (USAF)	61 10	150 00
Gilmore Creek (NASA)	64 58	147 30
Kodiak (USN)	57 49	152 30
Ulaska (NASA)	64 58	147 30

HAWAII

Kunia (USAF)	21 28N	158 04W
Pearl Harbor (USN) (Remote)	21 22	157 58

CANADA

Argentia, Newfoundland (USN)	47 18N	54 00W
Frobisher Bay, N. W. T. (Mobile)	63 45	68 30
Montreal, Quebec	45 30	73 36
Ottawa, Ontario	45 25	75 43
RCA Victor Co., Montreal Quebec	45 30	73 36

PUERTO RICO

Ramey AFB (USAF) (Remote)	18 31N	67 12W
San Juan (USWB)	18 29	66 08

CANAL ZONE

Howard AFB (USAF) (Mobile)	8 57N	79 34W

BERMUDA		
Kindley AFB (USAF)	32 22N	64 42W
ICELAND		
Keflavik Airport (USN)	64 01N	22 35W
UNITED KINGDOM		
Bracknell	51 26N	0 46W
High Wycombe AS (USAF)	51 38	0 46
London (USN) (Remote)	51 30	0 10
DENMARK		
Copenhagen	55 43N	12 34E
NETHERLANDS		
The Hague	52 05N	4 16E
WEST GERMANY		
Berlin	52 32N	13 25E
Braunschweig	52 15	10 30
Dortmund	51 32	7 27
Frankfurt (Offenbach)	50 06	8 41
Heidelberg (USAF) (Mobile)	49 25	8 42
Munich	48 08	11 35
Ramstein AB (USAF)	49 27	7 47
Wiesbaden (USAF) (Mobile)	50 05	8 15
POLAND		
Krakow	50 03N	19 55E
FRANCE		
Lannion	48 44N	3 27W
Evreux AB (USAF)	49 03	1 11E
SWITZERLAND		
Berne	46 57N	7 26E
Geneva	46 13	6 09

SPAIN		
Rota (USN)	36 37N	6 21W
Torrejon AB (USAF)	40 27	3 29
AZORES		
Lajes Field (USAF)	38 47N	27 10W
TURKEY		
Incirlik AB (USAF)	37 00N	35 19E
CYPRUS (U. K.)	35 N	33 E
PERSIAN GULF (U. K.)	27 N	51 E
ADEN		
Aden (U. K.)	12 46N	45 45E
MALAGASY		
Tananarive (NASA)	18 52S	47 30E
MALDIVE ISLANDS (U. K.)	4 N	73 E
INDIA		
Bombay	18 56N	72 51E
VIET NAM (South)		
Tan Son Nhut (USAF)	10 50N	106 38E
SINGAPORE		
Singapore	1 20N	103 50E
INDONESIA		
Bandung, Java	6 57S	107 34E
HONG KONG		
Kowloon (Royal Observatory)	22 18N	114 10E
TAIWAN		
Taipei AS (USAF) (Mobile)	25 05N	121 32E

PHILIPPINES		
Clark AB (USAF)	14 36N	120 59E
Cubi Point (USN) (Remote)	14 50	120 15
Sangley Point (USN) (Remote)	14 29	120 53
KOREA (South)		
Osan AB (USAF)	37 10N	127 04E
JAPAN		
Fuchu AS (USAF)	35 40N	139 29E
Tokyo	35 40	139 45
Yokosuka (USN) (Remote)	35 17	139 40
OKINAWA		
Kadena AB (USAF)	26 20N	127 45E
GUAM		
Agana NAS (USN)	13 29N	144 48E
Anderson AFB (USAF) (Remote)	13 35	144 55
MIDWAY ISLANDS		
Midway (USN)	28 15N	177 25W
FRENCH POLYNESIA		
Papeete, Tahiti	17 32S	149 34W
AUSTRALIA		
Darwin	12 23S	130 44E
Melbourne	37 45	144 58
Perth	31 58	115 49
NEW ZEALAND		
Christchurch (USN)	43 33S	172 40E
ANTARCTICA		
McMurdo (USN)	77 51S	166 37E

APPENDIX B

MAJOR RADIO STATIONS TRANSMITTING WEATHER FACSIMILE

The following is a list of the major radio stations transmitting facsimile weather charts. In some cases, the area in which the broadcast is intended to be received has been included. Most of the broadcasts are non-directional, but where known, the mean azimuthal bearing of beamed transmissions has been included. Information on the antenna power could not be obtained for all stations. Various sources were used to compile this listing, but the major references were the World Meteorological Publication No. 9. TP. 4- Weather Reports: Stations, Codes and Transmissions, Volume C: Transmissions, 1965; and the U. S. Navy Hydrographic Office Publication 118A & B- Radio Weather Aids (References 1 and 2 to the main body of this report).

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Kodiak, Alaska		NHB	2356	0600	1800
57.8N 152.5W		NHB	4825	0600	1800
		NHB	8622	0000	2400
		NHB	12817,5	1800	0600
		NHB	17045,6	1800	0600
Edmonton, Canada	15 Kw	VFE	5360	0000	2400
53.5N 113.0W	15 Kw	VFE	8184	0000	2400
	5 Kw	VFE	11615	0000	2400
	5 Kw	VFE	15770	0000	2400

Edmonton radio is designed to transmit to Resolute, N. W. T. Other receiving stations in Northwest Canada also copy the facsimile transmissions. As the major lobe of energy is oriented along an azimuth of approximately 20° true, reception by stations located outside of this fan of energy is problematical.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Halifax, Nova Scotia		CFH	4271	0000	2400
44.5N 63.5W		CFH	9890	0000	2400
		CFH	13510	0000	2400
		CFH	17560	0000	2400
San Francisco, Calif.		NPG	5345	0000	2400
37.8N 122.5W		NPG	9455	0000	2400
		NPG	14927,5	1500	1000
		NPG	18080	1800	0600
		NPG	21785	1800	0600
San Francisco, Calif.	20 Kw	WMK 27	7340	0400	1800
37.8N 122.5W	20 Kw	WMM 21	11460	0300	0400
	20 Kw	WMM 21	11460	1800	2000
	20 Kw	WMM 55	15700	0200	0300
	20 Kw	WMM 49	19715	2000	0200

Transmission beamed towards the South-West Pacific on a mean azimuthal bearing of 240°.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
San Francisco, Calif.		WMI 50	10190	0500	2030
37.8N 122.5W		WMH 95	15982.5	2030	0500

Transmission beamed towards the Far East on a mean azimuth bearing of 298°.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
New York, N. Y.	25 Kw	WFH 65	5360,5	2300	0930
40.7N 73.8W	25 Kw	WFI 57	7849,5	1930	1030
	25 Kw	WFK 27	17440	1230	1730
	25 Kw	WFK 63	13840	1100	1300
	25 Kw	WFK 63	13840	1700	1900
	25 Kw	WFK 70	10750,5	1000	1200
	25 Kw	WFK 70	10750,5	1830	2000

Transmission beamed towards Europe on a mean azimuthal bearing of 52°.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
New York, N. Y.		WFA 29	9290	0000	0400
40.7N 73.8W		WFA 56	6957.5	0400	1000
		WFA 29	9290	1000	1200
		WFD 63	13961.5	1200	2400

Transmission beamed towards South America on a mean azimuth bearing of 163°.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Washington, D. C.		NSS	3357	0000	2400
38.9N 76.9W		NSS	4975	0000	1030
		NSS	8080	0000	2400
		NSS	10865	2300	1900
		NSS	16410	0515	2400
		NSS	20015	0000	2400
Andrews AFB, Md.		KWAF	10185	0001	1700
38.9N 76.9W		KWAF	12201	0000	2400
		KWAF	14672	0000	2400
		KWAF	19955	0000	2400
		KWAF	4793.5	0100	2359
		KWAF	6912.5	0000	2400

This is a radio facsimile blind weather broadcast.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Buenos Aires, Argentina	5 Kw	LRO 69	5185	0115, 1908, 1955	
34.5S 58.5W	5 Kw	LRB 72	10720	2030, 2115	
	5 Kw	LRB 72	10720	1555, 1630	
	5 Kw	LRO 84	18093	1555, 1630	
Oslo, Norway	15 Kw	LCV	137,75	0350	0515
60.0N 10.6E	2,5 Kw	LMO 8	8057,5	0000	2400
Jeloy Radio: LCV	2,5 Kw	LMO 34	4642,5	0000	2400
Oslo Meteo: LMO	2,5 Kw	LMO 5	5945	0000	2400

Broadcast is intended to be received in Norway, Scandanavia and the fleet in northern waters.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Stockholm, Sweden	50 Kw	SAY 2	119,85	0300	0700
59.2N 18.1E	2,5 Kw	SMA 4	4037,5	0300	2100
Karlsborg: SAY	2,5 Kw	SMA 6	6901	0700	2100
Spanga: SMA					
Shannon Airport, Ireland	5 Kw	EIP	5768	0030	0230
52.7N 8.9W	5 Kw	EIP	5813	0030	0230
	5 Kw	EIP	8104	0030	0230
	5 Kw	EIP	3398	0630	0830
	5 Kw	EIP	5768	0630	0830
	5 Kw	EIP	5813	0630	0830
	5 Kw	EIP	8104	1230	1430
	5 Kw	EIP	12189	1230	1430
Bracknell, England	4 Kw	GFE 21	4780	0000	2400
51.4N 0.8W	4 Kw	GFE 22	9485	0000	2400
	4 Kw	GFE 23	13761	0000	2400
	4 Kw	GFE 24	18261	0000	2400

Broadcast is intended to be received in Europe, northern Africa (north to 20° N), and the western part of Asia as far as 60°E.

Paris, France	4 Kw	FTE 3	4035	0300	0800
49.0N 2.3E	4 Kw	FTE 3	4035	2015	2245
Ste Assise: FYA 36	4 Kw	FTI 8	8085	0300	2245
Pontoise: FTE 3, FTI 8,	4 Kw	FTM 26	12260	0815	2000
FTM 26	45 Kw	FYA 36	136,5	0300	2245

Broadcast is intended to be received in Europe and North Africa.

Paris, France	100 Kw	FYA 31	131,8	0000	2400
49.0N 2.3E	10 Kw	FTE 4	4047,5	2030	2400
Ste Assise	10 Kw	FTE 4	4047,5	0000	0700
	10 Kw	FPI 8/B	8185	0000	2400
	10 Kw	FTM 30	12305	0650	2050

Broadcast is intended to be received in Europe and North Africa.

Offenbach/Main, West Germany 50.1N 8.7E	50 Kw	DCF 54	134,2	0000	2400

Broadcast is intended to be received in Europe.

Offenbach/Main, West	20 Kw	DFQ 32	16332,5	0925	1131
Germany	20 Kw	DFM 28	12287	1600	1843
50.1N 8.7E	20 Kw	DFJ 94	9947	1958	2144

Transmission from Offenbach to Nairobi, Kenya.

Kindsbach/Ramstein AB,	3 Kw	EDIM	2980	0000	2400
West Germany	3 Kw	EDIM	7835	0000	2400
49.5N 7.8E	3 Kw	EDIM	4767	0000	2400
	3 Kw	EDIM	11440	0000	2400

This is a radio facsimile blind weather broadcast.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Moscow, USSR		RCI 72	3875	1530	0515
51.0N 38.0E		RWW 79	4550	1940	2125
		RWW 79	4550	0150	0405
		RVO 73	5150	1035	1640
		RVO 73	5150	1940	2125
		RND 77	5355	0000	2400
		RAN 77	6880	0150	0405
		RAN 77	6880	1035	1640
		RAN 77	6880	1940	2125
		RAW 78	7750	0535	0305
		RKA 78	10230	0150	0405
		RKA 78	10230	1035	1640
		RDD 78	10980	0330	1310
Moscow, USSR		RWW 79	4550	1700	0515
51.0N 38.0E		RVO 73	5150	0550	1905
		RAN 77	6880	0000	2400
		RKA 78	10230	0430	0940
Rota, Spain		AOK	5420	0000	2400
36.6N 6.4W		AOK	12184	0000	2400
		AOK	19019	0000	2400
		AOK	9105	0300	1700
		AOK	16185	0700	2000
Torrejon AB, Spain	3 Kw	LETO	4600	0000	2400
40.5N 3.5W	3 Kw	LETO	9172.5	0000	2400
	3 Kw	LETO	6875	0000	2400
	3 Kw	LETO	16218	0000	2400
	3 Kw	LETO	20218	0000	2400
Cairo, U.A.R.	3 Kw	SUU 7	3957	2020	2140
30.2N 31.5E	5 Kw	SUU 3	7317	0830	0940
				1130	1225
				2020	2140
	5 Kw	SUU 30	10893	0830	0940
				1130	1225
				2020	2140
	5 Kw	SUU 9	18106	0830	0940
				1130	1225

Broadcast is intended to be received in Africa, Europe and West Asia.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Nairobi, Kenya	10 Kw	5YE 4	5127	1800	0600
1.5S 37.0E	10 Kw	5YE	9043	0000	2400
	10 Kw	5YE 3	17365	0600	1800

Broadcast is intended to be received within a 4,000 mile radius of Nairobi.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
New Delhi, India	5 Kw	VVD 62	12075	1000	1250
28.2N 77.0E	5 Kw	VVD 69	19400	1000	1250

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Khabarovsk, USSR		RSJ	3250	0925	2320
48.2N 135.1E		RSJ 2	4516,7	0000	2400
		RSJ 3	3855	0925	2320
		RSJ 3	7475	0000	2400
		RSJ 3	14737	2340	0905
		RSJ 5	9230	2340	0905
Tokyo, Japan	5 Kw	JMH	3622,5	0000	2400
35.7N 139.8E	5 Kw	JMH 2	7305	0000	2400
	5 Kw	JMH 3	9970	0000	2400
	5 Kw	JMH 4	13597	0000	2400
	5 Kw	JMH 5	18220	0000	2400
	5 Kw	JMH 6	22770	0000	2400
	5 Kw	JMB 40	4902	0020	0530
	500 W	JMB 40	4902	0620	2335
Tokyo, Japan	2.5 Kw	RJTZ	3205	0000	2400
Fuchu AS	2.5 Kw	RJTZ	5960	0000	2400
35.7N 139.5E	2.5 Kw	RJTZ	6940	0000	2400
	2.5 Kw	RJTZ	7938	0000	2400
	2.5 Kw	RJTZ	10275	0000	2400
	2.5 Kw	RJTZ	13450	0000	2400
	2.5 Kw	RJTZ	15798	0000	2400
	2.5 Kw	RJTZ	20885	0000	2400

This is a non-directional radio facsimile weather broadcast.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Canberra, Australia	5 Kw	AXM 32	5100	0000	2400
35.3S 149.0E	10 Kw	AXM 34	11030	0000	2400
	20 Kw	AXM 35	13920	0000	2400
	20 Kw	AXM 37	19690	2200	1000

Broadcast is intended to be received from the Equator southwards.

Name & Location	Antenna Power	Call Sign	Frequency (kc/s)	Time(GMT) From	To
Guam, Mariana Islands	40 Kw	NPN	4975	0700	1900
13.5N 144.8E	30 Kw	NPN	7645	0700	1900
	40 Kw	NPN	10255	0000	2400
	40 Kw	NPN	13807,5	0000	2400
	40 Kw	NPN	18620	1900	0700
	40 Kw	NPN	23880	0000	2400
Pearl Harbor, Hawaii	20 Kw	NPM	4802,5	0600	1800
21.4N 157.0W	20 Kw	NPM	9440	0000	2400
	20 Kw	NPM	13862,5	0000	2400
	20 Kw	NPM	16400	1800	0600

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APPENDIX C

A POSSIBLE METHOD FOR ESTIMATING THE PROBABLE AREAS OF COVERAGE OF HF RADIO FACSIMILE TRANSMISSIONS*

C.1 General

An accurate determination of the coverage areas of the present HF radio weather facsimile transmitters (approximately 30) could readily be made if the antenna patterns were available. The antenna patterns, along with transmitter characteristics and up-to-date ionospheric measurements, could be used in a computer program, similar to the one developed by the Central Radio Propagation Laboratory (CRPL, Ref. 5), to obtain coverage areas for any given month.

To calculate the coverage of a single station, the CRPL handbook and monthly ionospheric predictions (Ref. 6) would be used. The task of going through these calculations for more than one station is quite involved, and is best done by computer.

An alternative to the above approach is to arrive at a maximum range estimate, based on a simple path approximation using the well known Transmission Path or Range Equation (Ref. 1).

Weather facsimile data are transmitted at high frequencies, in the range of 3 to 30 Mcs. Data can be received directly (ground wave transmission, limited to 300 km), or by ionospheric reflection (sky wave).

Sky wave propagation for long distances is accomplished via the F_2 layer. In this case, the operating frequency must be high enough to penetrate the lower E and D layers, and low enough to reflect from, rather than pass through, the F_2 layer. E and D layer absorption takes place only in the daytime; but, in order to arrive at a general, worst case estimate, the daytime absorption figures will be used for all calculations.

Because of the many variables involved in ionospheric propagation, the lack of detailed data on the transmission links (antenna patterns, local propagation characteristics, etc.), and the amount of effort required for a detailed, up-to-date coverage study, the following general assumptions seem reasonable and will be made:

1. Transmitting antenna: Meteorological data are intended for many local users (those within a range extending out from the station some 2000 to 4000 km) with unsophisticated receivers. Accordingly, the antenna pattern is assumed omnidirectional; i.e., a hemisphere centered about the transmitter. The ground coverage from this

* This Appendix was prepared by Mr. Anthony J. Petrella.

pattern is assumed continuous, such that ground wave propagation prevails up to 300 km and sky wave propagation thereafter. A gain of unity ($G_t = 1$) will also be assumed for the transmitting antenna.

2. Receiving antenna: A vertical, omnidirectional antenna with unity gain ($G_r = 1$).

3. Receiver: A simple vacuum tube device, with a noise figure of around 10 db, is assumed.

4. Transmitting frequencies: It is assumed that the station frequencies have been selected for optimum, relatively local coverage. This means that they correspond to the lowest, local Optimum Transmission Frequencies (see FOT, Ref. 2). The CPRL ionospheric predictions are merely plots of Maximum Usable Frequency (see MUF, Ref. 2) for different months of the year. Figures 1 through 12 of Ref. 5 show typical prediction maps (for December 1958), which are frequency contours of MUF. Optimum transmission frequencies are also affected by the sunspot cycle (Figure A of Ref. 6), and by the sun's zenith angle (Figures 23 through 34 of Ref. 5).

5. Propagation path: Only the single hop transmission path will be considered in detail here because of the assumption of local coverage. Energy radiated from the transmitter is reflected from the F_2 layer (altitude of 400 km), and the transmission path (R) is approximately the ground distance for path lengths of 3-4000 kilometers. In those cases where lower frequencies are used, a lower layer (E or F_1) path is assumed.

Using the assumptions listed above, a range estimate, which defines the radius of the circular coverage area (centered at each transmitting site) can be obtained by use of the Range Equation of Ref. 1.

C.2 The Range Equation

In the following Range Equation, the received carrier signal to noise ratio (SNR) is given as a function of all the variables of the communication link. The expression provides a ratio of signal to noise power, and each variable will eventually be expressed in db above one watt.

$$SNR = \frac{P_t G_t G_r}{kT_s B F L_p L_a L_f} \left(\frac{\lambda}{4\pi R}\right)^2 \quad , \text{ where}$$

SNR	=	Carrier Signal to Noise Ratio at receiver IF
P_t	=	Transmitter power (watts)
G_t	=	Transmitting antenna gain
G_r	=	Receiver antenna gain
R	=	Path length in meters

k = Boltzmann's constant, 1.38×10^{-23} joules/°Kelvin

T_s = Effective noise temperature of receiving system (sky temperature)

F = Receiver Noise Figure

B = Noise bandwidth of receiver IF

L_p = Polarization loss

L_a = Ionospheric absorption loss

L_f = Focusing factor

λ = Wavelength in meters

The above parameters adequately describe the characteristics of a single hop, high frequency radio link. By using the SNR requirement for such a link, as established by the CCIR (Ref. 7), the above equation can be solved for R, given P_t and the transmitter frequency.

C.3 Ionospheric Loss Factors

Before proceeding with the solution of the range equation, loss factors $L_p + L_a + L_f$ should be discussed briefly.

L_p - Polarization Loss: When a wave propagates in the ionosphere, its polarization varies as a function of its frequency, the ionosphere's electron density, and the earth's magnetic field. The decision as to the best polarization for a given station is made by considering the polarization of the receiving antenna, and the direction of propagation with respect to the magnetic equator. Since no information on the polarization of the several stations is available, the gross case of a linearly polarized antenna receiving a circularly polarized wave will be assumed. For this case L_p = 6 db (Ref. 2).

L_a - Absorption Loss: This loss exists in the daytime, and is caused by absorption as the wave passes through the E and D layers. L_a contributes 6 to 10 db of signal to noise ratio degradation (Ref. 2).

L_f - Focusing Factor: It is quite difficult to treat focusing of ionospherically reflected radio signals without a detailed analysis of the local ionosphere. Focusing or defocusing has the effect of converging or diverging the transmitted energy. The effect is the same as increasing or decreasing the path length, and the focusing factor can be 6 to 9 db.

The worst case of ionospheric loss is given by:

$$L_I = L_p + L_a + L_f = 6 + 10 + 9 = 25 \text{ db}$$

C. 3. 1 Path Losses (2 or more hops)

The maximum, one hop, transmission range is approximately 4000 km; and links of greater length must use E layer or ground reflection. If more than one hop is used, the 10 db absorption loss (see above) must be multiplied by the number of hops.

In the event that ground reflection occurs, a worst case loss for poor ground reflection (poor conduction) is 3 db. For the purpose of this estimate, however, it will be assumed that frequencies above 10 Mcs are used in a one hop link using the F_2 layer (height of 400 km).

Frequencies below 10 Mcs will be treated as E and F_1 layer paths, with a single hop distance of 2000 km. In this case, a 13 db SNR decrease will be assumed for each additional hop, to account for additional absorption and ground loss.

C. 4 Receiver Noise Power

Receiver noise power is given by the expression:

$$N_r = kT_sBF \text{ (watts)}$$

In the above equation, the units of kT_s are watts per cps. The receiver bandwidth, B, is in cps, and F, the receiver noise figure, is dimensionless. A worst case noise figure of 10 db is assumed, and is typical of a commercial grade vacuum tube receiver.

The noise figure, F, always given with reference to ambient temperature (290°K), will be converted to an equivalent receiver noise temperature, T_r, and added to the sky temperature, which is indicative of the noise level that the antenna must work against.

$$T_r = 290 \text{ (F-1) } ^{\circ}\text{Kelvin}$$

$$T_r = 2,610 \ ^{\circ}\text{Kelvin}$$

Revising the receiver noise power as described above gives:

$$N_r = k(T_s + T_r) \text{ B (watts)}$$

The magnitude of T_s is a function of how the earth, and the communication link in question, are oriented with respect to the galactic center, which is the primary source of sky noise. Maps are available which give contour lines of T_s in db above one watt (Ref. 2), but only the worst case will be considered here. A worst case sky noise temperature of 25×10^3 °Kelvin was obtained from References 1 and 8, which contain plots of sky noise temperature vs. frequency.

Assuming a 5,000 cps information bandwidth, the following receiver noise power is obtained:

$$N_r = (1.38 / 10^{-23} \text{ joules} / {}^{\circ}\text{K})(27{,}610^{\circ}\text{K})(5{,}000 \text{ cps})$$

$$N_r = 1.38 \times .276 \times .5 \times 10^{-23} \times 10^9 \text{ joules/ sec}$$

$$N_r = 1.9 \times 10^{-15} \text{ watts}$$

$$N_r \text{ (db)} = 10 \log_{10} 1.9 \times 10^{-15} = -147 \text{ db}$$

C. 5 Range Calculations

Having discussed the transmission path variables, we can now calculate the maximum communication range based on the desired SNR. It is again emphasized that the values of range (R) so obtained are only as accurate as the underlying assumptions.

Since the loss factors and receiver noise power (presented respectively in C. 3 and C. 4) are in units of power, and have been expressed in db above one watt, the Range Equation of C. 2 should be expressed in power levels and solved for R^2. Replacing receiver noise power with N_r, and ionospheric losses by L_I, we have;

$$SNR = \frac{P_t G_t G_r}{L_I N_r} \left(\frac{\lambda}{4\pi R}\right)^2, \text{ or}$$

$$R^2\text{(db)} = P_t + G_t + \lambda^2 + G_r - [SNR + N_r + L_I + (4\pi)^2],$$

where all quantities on the right hand side are now expressed in db above one watt. The first three quantities are functions of the particular transmitter whose range of coverage is desired, while G_r is a function of the receiving antenna. Based on the assumptions listed in C. 1, both G_t and $G_r = 0$, when expressed in db above one watt.

Reference 7 gives an RF carrier signal to noise ratio requirement of 27 db (above one watt) as an acceptable performance standard for an ionospheric link. This figure must be further modified to 29 db (Ref. 2) to include the effect of random (Rayleigh) signal fading. An investigation of the bases for these criteria is beyond the scope of this report. Since the signal to noise ratio is given as a power ratio in db, the equation parameters will be reduced to db (above one watt) in the examples given below:

Example No. 1: Single hop transmission path, using F_2 layer

The maximum range of coverage for a transmitter located at Nairobi, Kenya, which has the following characteristics:

Radiated Power	10 Kw
Frequency	17.365 Mcs
Position	15S, 370E
Call Sign	5YE 3,

is calculated below:

$$P_t(\text{db}) = 10 \log_{10} 10^4 \text{ watts} = 40 \text{ db}$$

$$\lambda = v/f = \frac{3 \times 10^8 \text{m/s}}{17.365 \times 10^6 \text{cps}} = 17.4 \text{ meters}$$

$$\lambda^2(\text{db}) = 10 \log_{10} (17.4)^2 = 25 \text{ db}$$

$$(2\pi)^2\text{db} = 10 \log_{10}(2\pi)^2 = 22 \text{ db}$$

Solving for R^2, by substituting the above levels and those from C.3 and C.4, gives:

$$R^2(\text{db}) = 40 + 25 - [29 - 147 + 25 + 22]$$

$$R^2 = 136 \text{ db}$$

$$R = 6,300 \text{ km}$$

Thus, using one hop path loss approximations, we arrive at a range greater than the maximum distance assumed for single hop transmission (4000 km). It is reasonable to assume that information arriving at receivers 6,300 km from the transmitter arrived there by more than one hop.

Insertion of an additional 10 db loss for the absorption loss of the second hop, and 3 db for ground reflection, gives a modified range of:

$$R^2 = 123 \text{ db}$$

$$R^2 = 2.0 \times 10^6$$

$$R \approx 1400 \text{ km}$$

It is then evident that, with the set of worst case assumptions, two hop transmission at 40 kw is not the dominant communication mode for long distances. The final conclusion is that single hop coverage to 4000 km will provide good signal quality, and a fringe area of marginal reception might extend for another 1000 km.

Example No. 2: Multiple Hop Transmission

Station 5YE 4 at Nairobi operates at the same power level as 5YE 3, but at 5.127 Mcs. Since the transmission frequency is below 10 Mcs, the assumption is made that short hop transmission is intended (C.3.1). A hop distance of 2000 km, and a minimum of 2 hops, are assumed.

$$\lambda = \frac{3 \times 10^8 \text{ meters/s}}{5.127 \text{ Mcs}} = 58.5 \text{ meters}$$

$$\lambda^2(\text{db}) = 10 \log_{10} (58.5 \text{ meters})^2$$

$$\lambda^2 = 35 \text{ db}$$

Adding 12 db loss for the additional hop, the expression obtained for R^2 in Section C.5 gives:

$$R^2 = 40 + 35 - [\,29 - 142 + 25 + 22 + 12\,]$$

$$R^2 = 134 \text{ db}$$

$$R = 5000 \text{ km}$$

Thus, two hop, lower frequency coverage takes care of approximately the same area as single hop coverage at a higher frequency. Station 5YE 4 operates twelve hours a day and 5YE 3 operates for the remaining 12, which indicates that both stations complement each others transmission and provide 24 hour coverage to the same user area. A third station, 5YE-Nairobi, operates all day, at 40 kw, on 9.04 Mcs. It seems probable that the 24 hour station compensates for any unpredictable fluctuations in ionospheric density, which might cause certain users to miss important data transmitted on either of the other two frequencies.

C.6 Applications to Estimates of Areas Deficient in Coverage by Radio Facsimile Weather Broadcasts

Analogous calculations were performed for a reasonable sample of the major radio weather facsimile transmitting stations listed in Appendix B. The worst case maximum range estimates extended from a low of 1600 km (for the 500 watt station at Tokyo) to a maximum of 7000 km (for the 40 Kw station at Guam). More typical values were within a general range extending from slightly less than 2000 km to slightly over 5000 km. An approximate mean would appear to be in the 4000-5000 km range.

When these very approximate findings are applied to the station locations listed in Appendix B and illustrated in Figure 2-2, it appears that the major areas of deficient radio facsimile coverage include:

a. Most of the tropical portions of the Atlantic Ocean

b. Most of the South Atlantic Ocean

c. Most of the central and eastern South Pacific Ocean

d. The central Indian Ocean, especially south of the equator

e. The Antarctic, and the Antarctic Ocean, except perhaps in those areas directly south of Australia and New Zealand

C. 7 Data and Approaches Required for Reasonably Precise Coverage Estimates

Significant further effort in this area would be required to increase the confidence factor in, or to usefully alter the data derived from, the above outlined approach.

There are two possible approaches, one principally theoretical and the other strictly empirical. The theoretical approach would require:

1. Obtaining antenna patterns, antenna gains, and elevation angles for the radio facsimile transmitters used for broadcasting meteorological charts.

2. Calculating skip distances and new signal/noise ratios based on these data.

3. Adjusting path loss factors, using present and predicted ionospheric characteristics, to determine the expected ranges of reception.

The empirical approach would involve the establishment of a program whereby international recipients of radio facsimile weather broadcasts would send local signal strength data to a central agency for mapping.

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APPENDIX D

MAPS TO BE TRANSMITTED, AS A FUNCTION OF ASCENDING NODE LONGITUDE

The several maps to be transmitted sequentially along any orbit are normally determined, as regards longitude, as the ones whose centers are nearest to the subsatellite track. These maps are determined, therefore, by the ascending node of the orbit, and each ascending node determines a set of six maps, one for each latitude band. The map sets (and so the map sequences) which are valid for any given ascending node interval can be determined from Table D-1. The intervals of ascending node have been listed on the basis of establishing a new interval whenever a map set differs, even by only a single map, from that for the previous ascending node interval.

In a very few cases, minor deviations from the maps specified in Table D-1 may be appropriate as a result of the non-integral number of orbits (12.7 for a 750 n.mi. orbit) completed each day. In such cases, the adjustment must be subjectively determined by considering map areas and types previously programmed for transmission, and the latest analyses and prognoses available for use.

Table D-1

Maps to Use for Specified Ascending Node Intervals

Ascending Node Interval	SOUTHERN HEMISPHERE			NORTHERN HEMISPHERE		
	Polar (SP)	Mid Latitude (SM)	Tropical (ST)	Tropical (NT)	Mid Latitude (NM)	Polar (NP)
0- 4.9W	0	0	0	0	0	60W
5W- 11.9W	0	0	0	0	30W	60W
12W- 16.9W	0	0	0	30W	30W	60W
17W- 24.9W	0	0	30W	30W	30W	60W
25W- 34.9W	0	30W	30W	30W	30W	60W
35W- 41.9W	0	30W	30W	30W	60W	60W
42W- 46.9W	0	30W	30W	60W	60W	60W
47W- 54.9W	0	30W	60W	60W	60W	60W
55W- 59.9W	0	60W	60W	60W	60W	60W
60W- 64.9W	60W	60W	60W	60W	60W	120W
65W- 71.9W	60W	60W	60W	60W	90W	120W
72W- 76.9W	60W	60W	60W	90W	90W	120W
77W- 84.9W	60W	60W	90W	90W	90W	120W
85W- 94.9W	60W	90W	90W	90W	90W	120W
95W-101.9W	60W	90W	90W	90W	120W	120W
102W-106.9W	60W	90W	90W	120W	120W	120W
107W-114.9W	60W	90W	120W	120W	120W	120W
115W-119.9W	60W	120W	120W	120W	120W	120W
120W-124.9W	120W	120W	120W	120W	120W	180
125W-131.9W	120W	120W	120W	120W	150W	180
132W-136.9W	120W	120W	120W	150W	150W	180
137W-144.9W	120W	120W	150W	150W	150W	180
145W-154.9W	120W	150W	150W	150W	150W	180
155W-161.9W	120W	150W	150W	150W	180	180
162W-166.9W	120W	150W	150W	180	180	180
167W-174.9W	120W	150W	180	180	180	180
175W-180W	120W	180	180	180	180	180

Table D-1 (cont)

Ascending Node Interval	SOUTHERN HEMISPHERE Polar (SP)	Mid Latitude (SM)	Tropical (ST)	NORTHERN HEMISPHERE Tropical (NT)	Mid Latitude (NM)	Polar (NP)
175E-179.9E	180	180	180	180	180	120E
168E-174.9E	180	180	180	180	150E	120E
163E-167.9E	180	180	180	150E	150E	120E
155E-162.9E	180	180	150E	150E	150E	120E
145E-154.9E	180	150E	150E	150E	150E	120E
138E-144.9E	180	150E	150E	150E	120E	120E
133E-137.9E	180	150E	150E	120E	120E	120E
125E-132.9E	180	150E	120E	120E	120E	120E
120E-124.9E	180	120E	120E	120E	120E	120E
115E-119.9E	120E	120E	120E	120E	120E	60E
108E-114.9E	120E	120E	120E	120E	90E	60E
103E-107.9E	120E	120E	120E	90E	90E	60E
95E-102.9E	120E	120E	90E	90E	90E	60E
85E- 94.9E	120E	90E	90E	90E	90E	60E
78E- 84.9E	120E	90E	90E	90E	60E	60E
73E- 77.9E	120E	90E	90E	60E	60E	60E
65E- 72.9E	120E	90E	60E	60E	60E	60E
60E- 64.9E	120E	60E	60E	60E	60E	60E
55E- 59.9E	60E	60E	60E	60E	60E	0
48E- 54.9E	60E	60E	60E	60E	30E	0
43E- 47.9E	60E	60E	60E	30E	30E	0
35E- 42.9E	60E	60E	30E	30E	30E	0
25E- 34.9E	60E	30E	30E	30E	30E	0
18E- 24.9E	60E	30E	30E	30E	0	0
13E- 17.9E	60E	30E	30E	0	0	0
5E- 12.9E	60E	30E	0	0	0	0
0 - 4.9E	60E	0	0	0	0	0